SERIES A (Freshwater) No. 36 1992

IRISH FISHERIES INVESTIGATIONS

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Christopher Moriarty
(Editor)

Papers presented to the 7th Session of the EIFAC
Working Party on Eel

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Roinn na Mara

(Department of the Marine)

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Irish Fisheries Investigations Series A (Freshwater), No. 36 (1992).

Introduction

by

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The Seventh Session of the Working Party on Eel of the European Inland Fisheries Advisory Commission was held in the Royal Hospital, Kilmainham, Dublin at the kind invitation of the Government of Ireland. A full report of the session, including names of the 52 participants and a list of all presentations has been published by FAO (Rome) as *EIFAC Occasional Paper No. 25.*

The present volume contains peer-reviewed papers and abstracts of other presentations to the session. The material is arranged under the headings of the six sub-groups of the Working Party and covers a very wide range of studies of the eel in wild and cultured conditions.

The Working Party, which meets in alternate years, has frequently considered its terms of reference and has on each occasion concluded that, because of the enormous geographical range and variety of habitats of the species of *Anguilla,* the primary need in research continues to be local studies of their basic biology. However, there is scope for international collaboration. Agreement has been reached by the Working Party on the most satisfactory methods of age determination and tagging and a handbook on these topics was published in 1988 as *EIFAC Occasional Paper No. 21.* Proposals were made at the Seventh Session for international co-operative studies on recruitment and on growth.

Grateful acknowledgement is made for the assistance of colleagues who formed the Editorial Board for this publication: Inge Boëtius, Yves Desaunay, Brian Knights, Russell Poole and Häkan Wickstrom.

Fluctuation of glass eel migration in the Mondego estuary (Portugal) in 1988 and 1989

by

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ABSTRACT

The drastic reduction in the quantity of glass eels entering estuaries in recent years, reinforced the need to review the legislation of the fisheries, as well as to promote studies aiming at the correct management of such an important resource.

A study on the fluctuation of glass eel migration was performed in the lower part of the Mondego estuary in 1988-1989.

Although the freshwater flow seems to be a ruling factor in the ascent of glass eels in this estuary, the results obtained show a variable pattern which is not easily interpreted, confirming the complexity and unpredictability of this migration.

INTRODUCTION

The fishery for glass eels in Portugal has been regulated by law since 1985. This legislation concerns only the estuarine waters. The official fishing season extends from 1 November to 28 February and the only permitted gear is a hand net called "rapeta".

Official data on glass eel catches before 1985 are rare mainly because the previous legislation did not oblige fishermen to apply for fishing licences and to report their catches. Numbers of fishermen and quantities captured are therefore mostly unknown.

More recently, the application of the law has been given considerable attention from the authorities. Despite all this, the official data available today are still underestimates.

Knowledge on abundance and preferences of glass eels during their upstream migration is poorly documented in Portugal. Apart from Mondego (Jorge and Sobral, 1989) and Minho (Weber, 1986) estuaries no studies have been published.

In order to obtain information about the current status of the glass eels in river Mondego, a survey was conducted from 1988 to 1990. The objectives were to examine and compare abundance and environmental preferences of glass eels during migration. Special attention was devoted to studying their abundance related to temperature and salinity.

MATERIAL AND METHODS

The estuary of Mondego is divided into two channels (Fig. 1), north and south which differ in width and depth.

This study was conducted in the north channel since the south channel is too shallow, during low tide, to permit the use of big nets.

Each month, from January 1988 to February 1990, the quantity of glass eels entering the estuary at new moon, was estimated by passive fishing using a fixed net called "tela" (Fig. 2) always set at night and at the same site during the sampling period.

The net, with a height of 5.8 metres, was set at low tide and the fishery was performed during the flood tide. The glass eels, trapped in the "tela", were caught with a hand net close to the boat where a lamp with a fading light illuminated the nearby water surface (Fig. 2). The duration of fishing was determined by the flood intensity and it lasted until the buoys sank.

Water temperatures and salinites at the surface and near the bottom were measured every 15 minutes during the fishing.

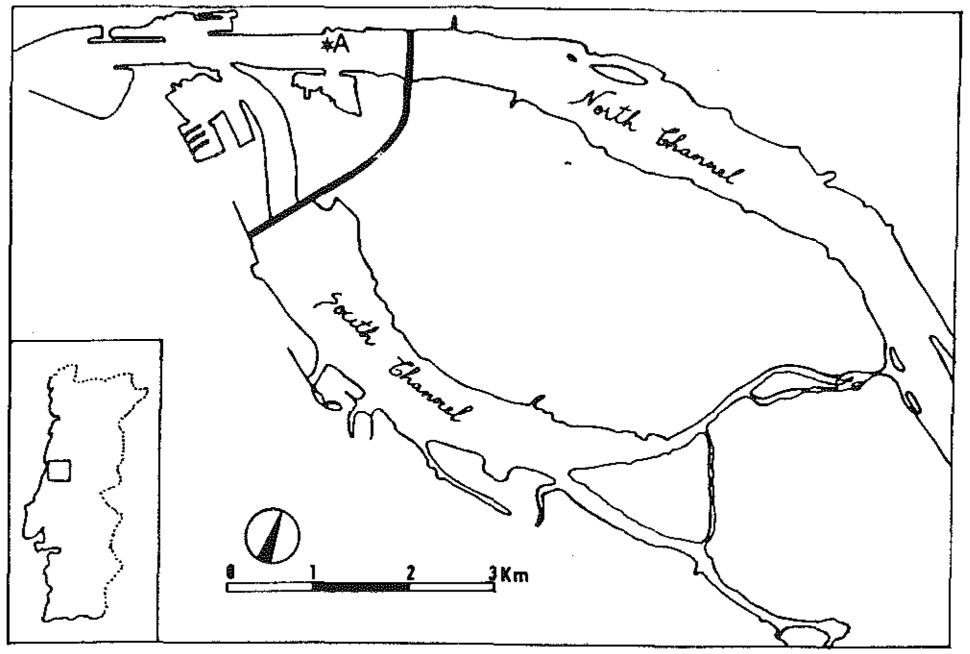

Figure 1. Location of sampling sites at Mondego estuary.

RESULTS

Total catches

Table I shows the monthly catches of glass eels during the sampling period.

The first fact which emerged was that glass eels were always present in the Mondego estuary although the number of individuals dropped considerably in summer. Peaks of abundance based on total catches, were usually recorded during the official fishing season showing that the period of more intense migration occurs during that time although it can be extended to March as happened in 1988.

A year to year decrease was observed. The mean quantities recorded during the fishing seasons of 1987/88, 1988/89 and 1989/90 were 941g/h, 588g/h and 384g/h respectively. Data from November and December 1987 were taken from Jorge and Sobral (1989).

Temperature

The water temperature varied from 9.7 to 23.0°C at the surface and from 10.1 to 22.6°C near the bottom. During the most important period of migration temperature ranged from 9.7 to 17.7°C at the surface and 10.1 to 18.3°C near the bottom.

Salinity

A comparison between salinity values recorded in 1988 and 1989 shows that during the second year, the salinities were lower as a result of more intense rainfalls and consequently, a higher river flow.

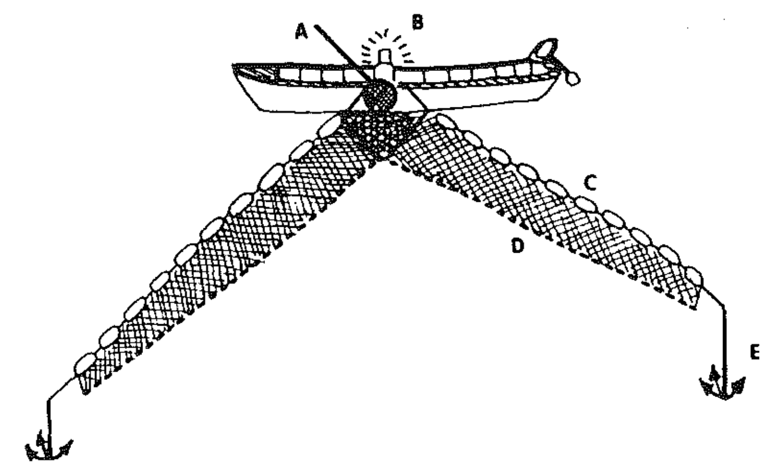

Figure 2. Passive fishing with *Tela* net. A - hand net, B - lamp, C - buoys, D - weights, E - anchor.

DISCUSSION

The water temperatures at which migration was more intensive were variable suggesting that migratory activity is related to some other seasonal influences since it occurs during winter months. According to Tongiorgi et al (1986) the thermal preference of *Anguilla anguilla* glass eels changes in relation to different environmental conditions. Naismith and Knights (1986) stated that the most intensive migratory activity does not appear to be temperature-related which is in part agreement with our results.

Glass eels are recorded in the Mondego estuary all year round but their abundance is usually favoured by high river flow. This confirms the concept of migration as being dependent upon river flow, put forward by Gascuel (1987) for the glass eels of the Sèvre Niortaise.

The attraction of glass eels to freshwater stated by Creutzberg (1961) and Deelder (1958) was probably favoured by the hydrological regime of the river and caused higher catches during 1988. The mean catches were 581g/h during 1988 and 407g/h during 1989. Furthermore it seems that rainfall increased the ascent of glass eels and gave surprising catches in July 1988. Intense rainfall, not common during summer, reduced the salinity values to the lowest recorded during the entire sampling period.

It appears however that heavy rainfall can also have a negative effect on the migration as happened in December 1989 and January 1990. The pluviometric data and the salinity values recorded during these months (Table I) indicate that the river flow was too strong to enable glass eels to proceed with their migration using the flood tide. This is in agreement with McCleave's and Kleckner's (1982) statement that glass eels adjust their behaviour depending upon hydrographic conditions to ensure rapid landward transport and select the flood tide to be off the bottom.

The results obtained in the two years of sampling indicate that rainfall is one of the most important factors influencing migration. It has a local and a wide scale effect on the glass eels arriving at the coastal waters every year. It increases the river flow diminishing salinity and changing the intensity and extension of the current during flood and ebb tide. All these aspects seem to be beneficial from October onwards due to the beginning of the rainy season.

Glass eels are no doubt able to withstand a great variety of environmental impact in terms of temperature, salinity, currents and many other factors but the success of migration will depend on the intensity of the rain and consequently on river flow and its impact on the water circulation in the estuary.

ACKNOWLEDGEMENTS

I thank Prof. Luiz Saldanha for his support, the staff at the INIP (Instituto Nacional de Investigação das Pescas), Figueira da Foz and Aveiro for kind cooperation during the sampling surveys and Prof. Maria José Costa and Dr. Sobral for scientific assistance.

Pluviometric data were kindly supplied by INMG (Instituto Nacional de Meteorologia e Geofísica).

This research was partly supported by a grant from JNICT (Junta Nacional de Investigação Científica e Tecnológica).

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Table 1. Results from passive fishing at sampling site A at new moon except where indicated by *. Maximum and minimum values of temperature (°C) and salinity (‰) on each occasion; total rainfall for month (mm).

Date	Fishing time (min)	Yield (g/h)	Temperature		Salinity		Rainfall
			Surface	Bottom	Surface	Bottom	
1988 Jan 19	65	373.85	—	—	—	—	169
Feb 17	70	1,800.00	—	—	—	—	89
Mar 18	70	2,562.86	15.5/15.1	15.5/14.2	17.0/ 4.6	30.9/ 7.3	6
Apr 16	83	321.69	17.1/16.0	—	15.0/ 6.0	—	82
May 15	80	83.25	15.3/15.1	—	0.6/ 0.3	—	136
Jun 14	87	68.97	19.0/18.0	18.8/16.2	32.1/ 6.0	32.5/ 9.8	64
Jul 13	150	364.00	20.0/17.7	20.0/14.1	20.8/ 0.2	34.8/ 0.4	97
29*	85	49.46	23.0/19.0	20.0/16.5	16.0/ 4.2	28.0/ 5.7	97
Aug 12	80	8.00	22.0/20.0	22.0/17.5	17.0/ 6.0	29.8/ 8.5	0
Sep 11	40	65.25	21.5/21.4	—	9.5/ 7.4	30.3/10.2	10
Oct 10	87	336.39	16.8/15.8	16.0/14.1	17.2/ 9.4	31.7/17.9	115
Nov 11	30	746.00	17.3/17.3	17.4/17.4	9.1/ 7.7	28.4/21.3	67
Dec 12	61	252.13	11.3/10.9	14.0/12.0	11.0/ 5.8	32.0/13.0	25
1989 Jan 7	137	823.36	12.0/ 9.7	12.9/10.0	28.6/ 5.8	32.3/ 6.7	33
Feb 6	80	495.00	12.3/12.0	14.5/13.0	26.0/13.1	34.5/32.0	134
Mar 7	43	195.89	—	—	—	—	55
Apr 6	20	112.20	13.2/13.0	13.4/13.1	15.0/ 3.9	21.1/ 4.1	107
10*	163	47.93	13.5/12.6	13.5/13.2	11.6/ 1.8	29.8/ 3.0	107
Jun 3	63	36.48	—	—	—	—	5
Jul 3	90	30.59	21.2/19.4	17.5/16.1	24.3/18.6	34.4/31.6	2
Aug 1	70	84.40	20.9/17.4	19.9/14.9	28.8/17.5	33.8/20.6	14
31	62	60.70	23.0/22.3	22.8/21.0	21.5/12.8	32.9/16.8	14
Sep 29	60	24.96	19.1/17.6	18.4/16.9	27.7/19.9	33.3/24.5	6
Oct 30	57	97.29	18.0/17.8	18.7/17.9	31.6/17.6	35.0/32.6	102
Nov 29	91	989.00	15.2/14.4	16.2/14.8	8.9/ 0.9	32.7/ 4.6	249
Dec 28	97	276.60	11.7/10.7	11.7/10.8	3.4/ 0.0	3.7/ 1.0	243
1990 Jan 15*	45	426.19	10.4/10.2	14.8/13.8	1.4/ 1.1	32.5/22.5	169
26	70	234.04	13.3/12.8	14.0/10.0	21.0/ 2.5	27.5/ 7.8	169
Feb 26	49	38.22	15.8/15.5	16.0/15.8	22.0/ 2.0	27.0/ 3.3	37

Glass eel arrivals in the Vilaine estuary (Northern Bay of Biscay) in 1990: Demographic features and early life history

by

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ABSTRACT

Glass eels were sampled monthly near the Arzal estuarine dam. Seventeen samples totalling more than 4,600 individuals, were examined for pigmentation stages. Length and age, through otolith microstructure observation, were established in spring (March to May) and in autumn (November and December). The arrival of new glass eels from the ocean was continuous, as indicated by the relative percentage of transparent individuals (stage V_B), although they were less numerous during summer. A new annual cohort was identified from September onwards, by longer individuals (63 mm mean length for stage V_B in May, vs 71 mm in September). Although the mean age appeared to decrease from 260 days (8.7 months) to 215 days (7.2 months). New hypotheses are proposed to explain the dynamics of the transatlantic migration.

INTRODUCTION

The present study deals with the description of samples of glass eels from the Vilaine estuary (47°30'00 W/02°23'00 N) in the northern part of the Bay of Biscay, downstream of an estuarine dam during 1990. The aim was to establish the timing of immigration through the year, and to make proposals for a better understanding of the oceanic migration from the offshore spawning area to the French coast. All the samples have not yet been studied, so results are still preliminary.

MATERIALS AND METHODS

Sampling Scheme (Table 1)

Samples were collected by glass eel nets from a boat at night just before high tide, during neap tides from the end of January 1990 to the beginning of December 1990, fortnightly from February to June and monthly after. After the closing of the official campaign, by 15 April, only experimental catches were carried on.

Pigmentation stages were determined according to Elie *et al.* (1982) in 17 samples totalling 4,621 individuals. Total length (mm) and weight (to the nearest 0.01g) were measured in 1,013 fresh individuals. Condition factor $k = (Wg/Lcm^3)10^3$ was calculated.

Otolith Preparation and Age Reading

Four samples caught in the estuary of the Vilaine (March, April, May and November 1990) and one sample from the Loire in December 1989 were preserved in 70% alcohol. For a preliminary description, the following sequence is considered: November, December, March, April, May, so as to constitute a logical evolution of the immigration. Sagittal otoliths were prepared and examined according to Lecomte-Finiger and Yahyaoui (1989). The otoliths were embedded in Promodentaire resin, ground and polished, then etched with EDTA, coated with gold and viewed under a scanning microscope (Hitachi S 520) at 20 kV. Photographs at various magnifications (x300, x1500) were used for counting increments and measuring their width. Growth rate was estimated on the assumption that growth increments were deposited daily. Growth rings were associated with early life stages as in Fig. 1. On every portion R_m and R_t, the total number of daily increments was counted, giving C (days from hatching to beginning of metamorphosis) and M (days from metamorphosis to arrival in coastal waters). In the following data, about six days must be added, to take into account the short period before hatching and resorption of yolk-sac. (Prokhorchik, 1986). In addition, the daily average incremental width was measured from ten successive rings in each part of the otolith, giving I_c and I_m. In some cases, exhaustive counting of the rings was difficult or impossible. This number was hence estimated by the ratio R_m/I_c or R_t/I_m.

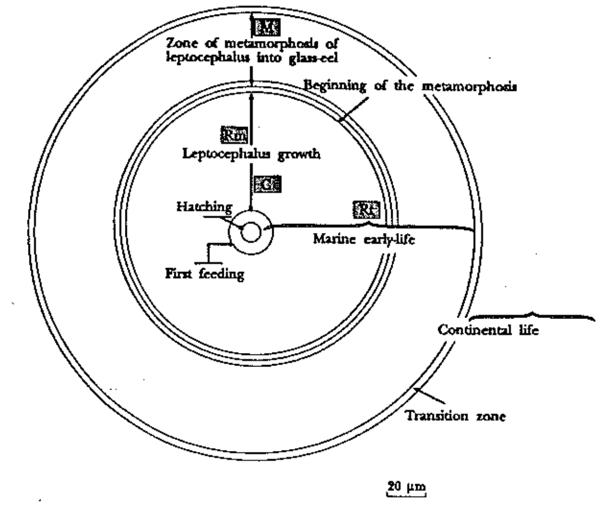

Figure 1. Identified structures and measurements of otolith.

RESULTS

Development of pigmentation

Stage V_B glass eels dominated samples, with other stages increasing in May-August (Fig. 2). Whatever the true age of these fishes, one can assume that the immigration begins in autumn (September) and is completed in the following summer (July-August).

Two notable features from Fig. 2 are (i) the lack of pigmented glass eels in the samples of January and early February, which might have derived from the autumn entering individuals; (ii) the immigration proceeds in "waves" during the first half-year. A survey of catches in the glass eel fishery shows five comparable waves of newly entered fishes in December, then from mid January to mid February and around 13 March, 12 April and 8 June. These two last waves, even if they are not so important in number, may significantly contribute to the fluvial recruitment, since they occur out of the fishing season and elvers can benefit from the best environmental conditions. It is not clear whether these waves of migration are related to tidal cycles or to successive micro-cohorts, themselves coming from periodic metamorphosis of leptocephali or discontinuous spawning.

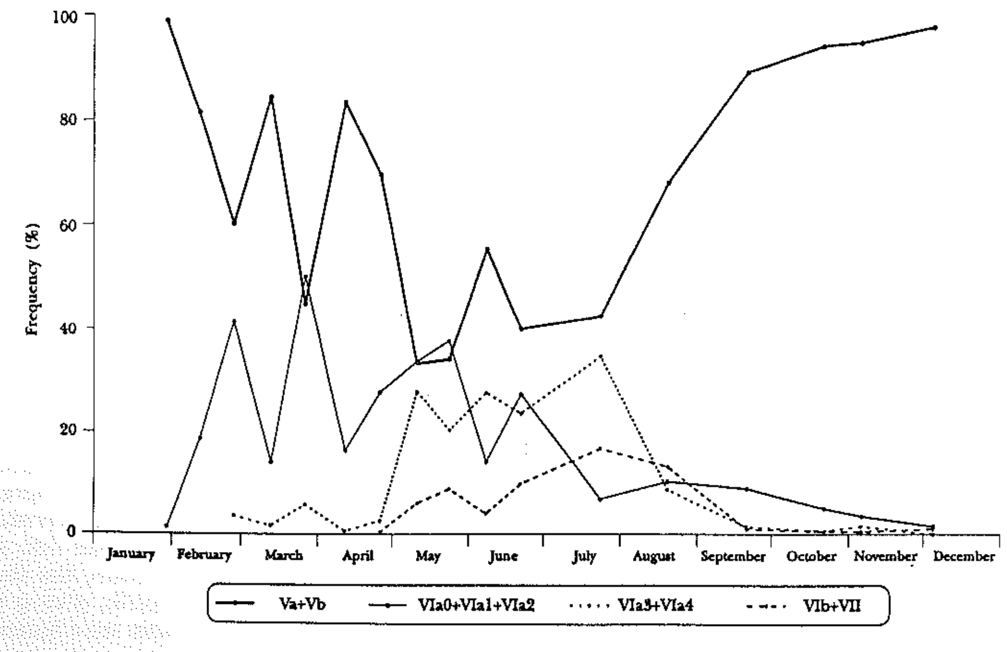

Figure 2. Frequencies of pigmentation stages in samples in 1990.

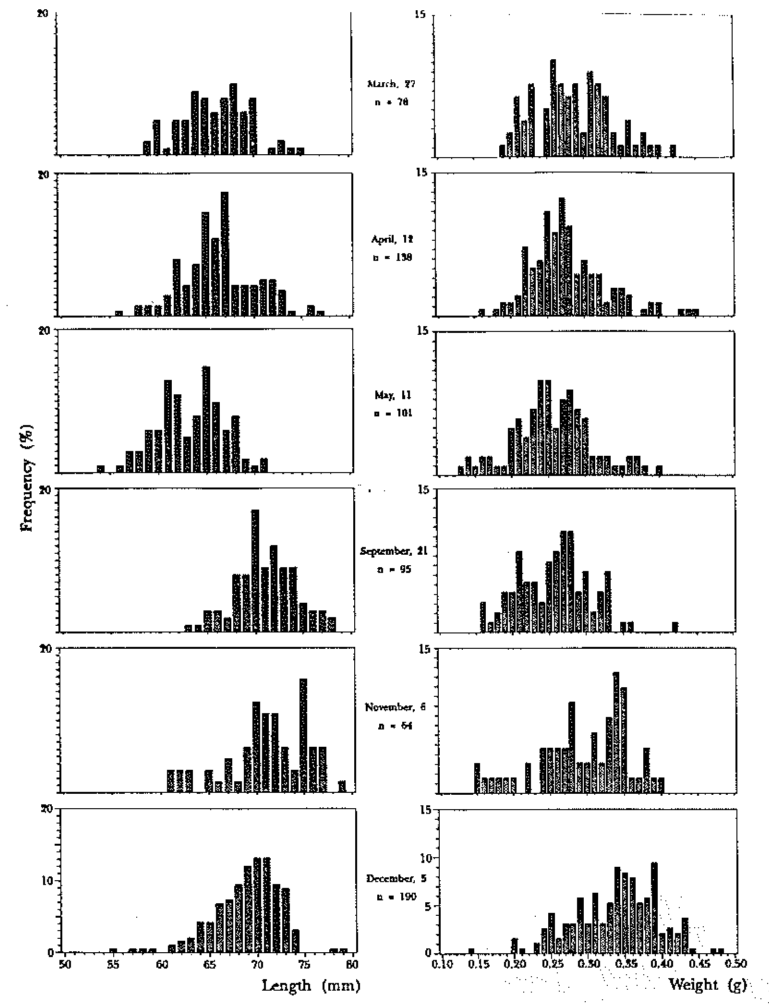

Figure 3. Frequency distributions of length (mm) and weight (g) in the samples.

Biometry

General features. Only V_B glass eels were considered here (Table 2). As found in many studies (even in *A. rostrata* elvers, Haro, 1987) there was a decrease in length of stage V_B glass eels, from 71.2 mm in September-November to 63.4 mm in May. The fresh weight first increases from September (0.26g) up to December (0.34g) then decreases from March onwards. A somewhat different figure is given in the western Mediterranean, with simultaneous decreases in both parameters (Chessa *et al.*, 1985) but mixing of pigmentation stages prevents a clear conclusion being reached.

Comparison between length and weight according to the season. Bearing in mind that the samples did not stem from a stable population, but from successive waves of newly arriving glass eels at stage V_B, the monthly characteristics have been tested (-t test, Table 3). Although the mean lengths were not significantly different between successive months during September-November and March-April, differences were highly significant between autumn and spring. This is not the case for the mean weights, in which a significant difference was found between the first (Sept.) or late (May) samples and the intermediate samples (December and March). This confirms that the first entering glass eels V_B and the last entering ones, with different lengths, both have reduced weights.

A more detailed examination of the distributions of length and weight (Fig. 3) suggests possible polymodal structures, according to the samples and the class-intervals. It appears hazardous to assume "sub-populations" exist, taking into account the variability in a given sample, which may be linked to a variable duration of the stage V_B.

The coefficient k is quite high, compared with other studies. The lowest values correspond to the first arrivals, in autumn i.e. to the longest individuals.

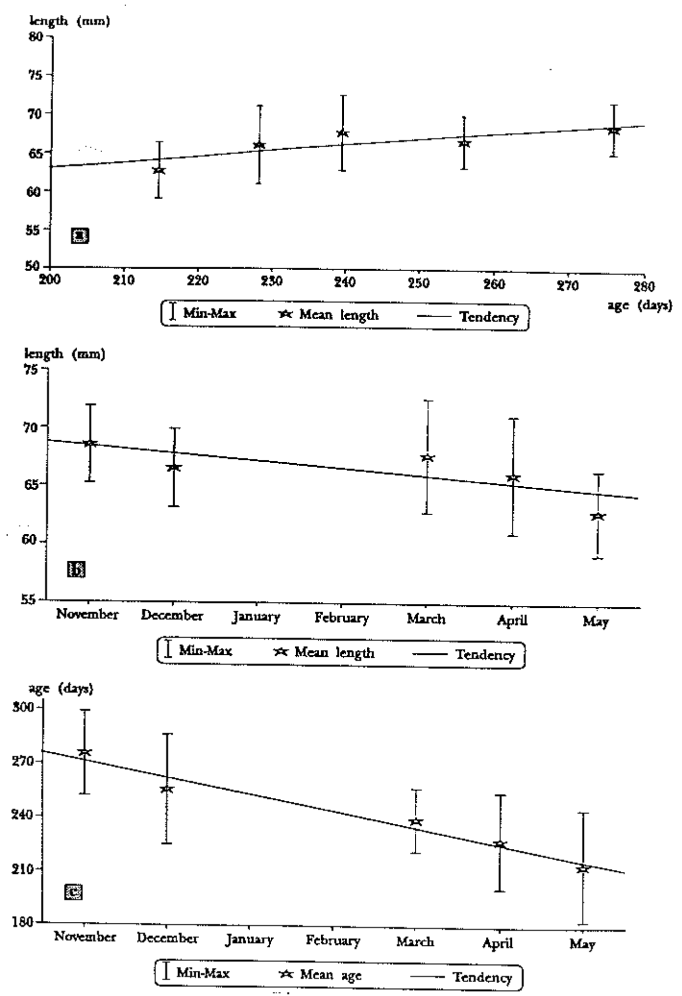

Figure 4. Comparison between relationships: (a) length-age; (b) length-date of sampling and (c) age-date of sampling, using mean values for each sample.

Age

From 113 otoliths examined, 85 provided complete results, 74 are from stage V_B (7 VI_{A0}, 1 VI_{A3}, 3 VI_{A4}). Only V_B glass eels will be considered here (Table 4 and Fig. 4). Results show that even if the interindividual variability is rather wide, the longest glass eels which arrive earlier, are older than the smallest ones. It is not possible to support the assertion that there is a reduction in size with age. It is more likely that the size of a glass eel entering an estuary is determined by the size of the former leptocephalus at metamorphosis.

Age and hatching date. Glass eels reaching coastal waters from autumn (November) to the following spring (May) belong to a unique cohort. The spawning period is very long: glass eels caught in November were born in February, those from May come from October spawners (Fig. 5). Considering the whole season of arrival, from the youngest individuals in May (157 days) to the oldest in November (312 days), it appears that spawning begins in late December and ends in next early December, almost one year later. However, numbers of spawners or eggs may vary enormously and a peak of spawning is likely to occur from April to July, corresponding to the fishing season (December to March). This is in agreement with Schmidt's (1922) previous conclusions.

Age and oceanic migration. The age of arriving V_B glass eels decreases from 276 days in November to 215 days in May. In other words, the duration of the oceanic journey decreases with time. This does not agree with the scheme proposed by Tzeng (1990) for *A. japonica* in which the ages increase with duration of migration. In both cases, however, the difference between the average ages does not match with the time-lag between the dates of sampling. As an approximation, given a distance of about 6,000 km, the mean migration speed varies between 28 km.d^{-1} (0.66 knot) and 23 km.d^{-1} (0.53 knot). This is consistent with Deelder's (1952) proposal for the mean speed in sea water (20 km.d^{-1}).

Growth rate analysis. Tzeng (1990) and Tsukamoto (1990) used the classical apparent somatic growth rate L/T, (total length of the fish in comparison with its age). The same ratio for the present data gives a growth

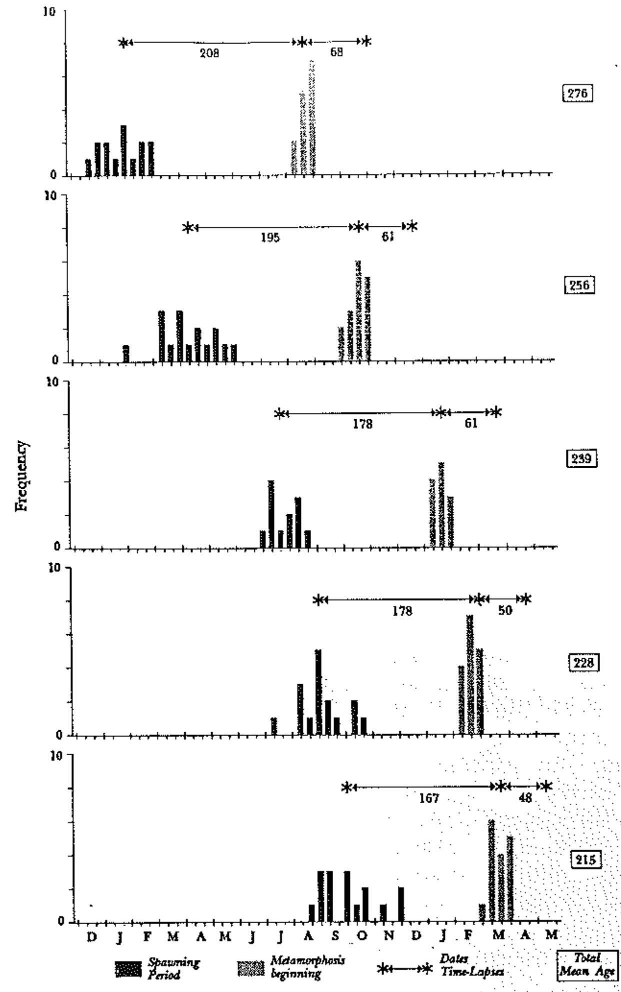

Figure 5. Spawning-period, beginning of metamorphosis and duration (days from hatching to sampling date) of the two larval phases, from back-calculation.

rate in the same range (Table 5) about 0.26 to 0.30 mm.d^{-1}. However, this formula does not fit for the glass eel, taking into account two oceanic stages

(i) the leptocephalus stage, during which the animal feeds and grows,

(ii) the glass-eel stage, during which the same animal starves, with very reduced growth.

Since the lengths of leptocephali are unknown, otolith size can be used to calculate three parameters:

(i) R_t/T, the apparent otolith growth rate,

(ii) R_m/C, the "leptocephalus" growth rate, and

(iii) $(R_t-R_m)/M$, the "glass eel" growth rate.

The latter assumes that, when the starving larva stops growing, the otolith still grows. This phenomenon was already described in sole larvae (Lagardère, 1989). The apparent otolith growth rate is 0.60 µm.d^{-1} to 0.65 µm.d^{-1}, which is inferior to *A. japonica* (Tsukamoto, 1989). This rate is constant in each stage, i.e. 0.51 to 0.56 µm.d^{-1} for the leptocephalus stage and 0.88 to 0.97 µm.d^{-1} for the glass eel stage. The lower value of 0.88 µm.d^{-1} is related to those individuals whose Atlantic journey and period of starvation (67 days) above the Continental Shelf were the longest.

DISCUSSION

Results are preliminary, and several limitations must be noted. Samples did not represent one unique

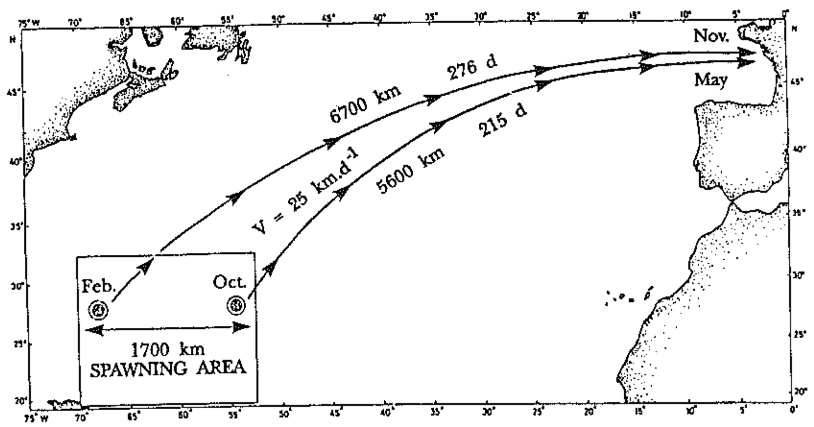

Figure 6. Longitudinal extent of the spawning area of European eels, showing assumed differences between journeys for larval from eastern or western spawning sites.

continuous cohort, but were comprised of parts of two successive cohorts (1989-1990 and 1990-1991), and even on one sample from a neighbouring estuary (Loire, December 1989), for otolith examination. Nevertheless, the evolution of pigmentation agrees well with the scheme proposed for a long time on the French Atlantic coast (Elie, 1979, for the same estuary, Gascuel, 1987 for the Sèvre Niortaise estuary, Cantrelle, 1981, in the Gironde) and in the south of the Bay of Biscay (Charlon and Blanc, 1982 near Bayonne). As far as age is concerned, two remarks must be added: (i) validation of the structures of the otolith has been possible in several cases. The "diffuse zone" was described by Boetius (1986) and was found in leptocephali at the beginning of their metamorphosis. Wider incremental zones were also found in sole larvae (Lagardère, 1989). Nevertheless the daily rhythm of otolith increments was established in the Conger Eel *Conger myriaster* leptocephali by Mochioka *et al.* (1989) and in *A. anguilla* elvers by Lee and Lee (1989); (ii) Since the transition ring is definitely laid down at stage VI_{A1} (Michaud *et al.,* 1988), there is little risk in using the date of sampling of stage V_B glass eels for back calculation.

The appearance of younger fish from November to May could be explained by two hypotheses: (1) A seasonal variation of the oceanic transport, and (ii) the extent of the spawning area:

(i) Starting from the same point in the Sargasso Sea, the last individuals spawned in autumn cross the ocean during winter, at relatively high speed and they arrive with a low mean size (63 mm) and a high coefficient of condition. This relatively high speed cannot be due to a higher metabolism of leptocephali, because of the lower planktonic productivity in winter. It is more likely related to a higher velocity of oceanic currents, which would correspond to the higher occurrence of the atmospheric depressions going eastwards. Conversely, the first spawned eels cross the ocean during summertime, when the anticyclone of the Azores is widely extended, and they take a lesser advantage from an advective drift. Although they stay longer in a richer trophic environment, favouring the growth of leptocephali, a longer journey above the shelf is not so profitable for starving glass eels. This would explain why the first glass eels entering the estuary have a higher length (70 mm), but a relatively low coefficient of condition (K = 0.71 in September). The same idea was proposed by Boetius and Boetius (1989). These seasonal variations are also consistent with the transatlantic mean advection: according to Worthington (1977), "Gulf Stream is strongest in late winter and weakest in late autumn".

(ii) Another explanation would relate to the extent of the spawning area, in time and in space. The duration of migration depends upon the distance from the starting point (Fig. 6). Given a constant speed (mean current velocity), the difference d_2-d_1 between extreme locations in the spawning area is estimated by $d_2 - d_1 = (t_2 - t_1)v$, where t_1 is the age of glass eels originating from the farthest spawning, t_2 the age of the nearest ones. Values of the North Atlantic Drift are taken from Wegner (1982) and Scheltema (1971) in Lecomte-Finiger and Yahyaoui (1989)

$$d_2 - d_1 = (276 - 215)v = 61\ v$$

According to the assumed current speeds, from 15 to 35 km.d^{-1}, (mean value 25 km.d^{-1}) the west-east extent of the spawning area varies from 915 to 2,135 km, (average 1,525 km). This range is consistent with the extent of the spawning areas proposed by Schmidt (1922) or Schoth and Tesch (1982) and McCleave *et al.,* (1987). An additional source of variability may stem from a preliminary clockwise larval drift, due to the anticyclonic gyre described by Tesch and Wegner (1989). As a consequence, longer/older *A. anguilla* larvae can be found in the western part of the spawning zone, which means that the actual distance/duration to the European coast may be longer than measured on the map.

CONCLUSION

For the first time, it has been possible to characterize a whole year of recruitment, with estimates of the absolute age of glass eels. Results are still preliminary but allow an updated proposal for the early life of *Anguilla anguilla.* During a one year period, from September to the next summer, only one year-class recruits to the estuary. A continuous immigration of stage V_B glass eels results from an almost continuous spawning. The oceanic flux is variable according to either seasonal variations in north Atlantic Drift efficiency or to the longitudinal extent of the spawning areas or even both. Corresponding to the most important period of immigration, which is the fishing season (December to March), the main spawning period is between April and July, which does not contradict Schmidt's (1922) hypothesis. One major result of the present study is the revision of the mean age of entering glass eels. From Schmidt (1922), to Schoth and Tesch (1982), then Boetius and Harding (1985), and finally Lecomte-Finiger and Yahyaoui (1989), the age estimate varied from about 3 years, to 12-15 months, or 12-18 months, and finally 5-7 months. The present results provide a range of 7-9 months for a major part of the run of glass eels.

Further studies are necessary to model the early life history of *Anguilla anguilla.* A better validation of microstructures marking larval phases is needed. A new sampling scheme, improving the statistical values, during one continuous season of migration, will also be necessary. Finally, a comparison of several species' (*A. anguilla, A. rostrata* and *A. japonica*) larval migrations, related to oceanographic features (topography, current velocity, impact of climatic cues) could allow a better understanding of the mechanisms of recruitment.

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Table 1. Origin of samples and number of observations.

Estuary	Dates	Pigmentation	Observations Biometry Total	Observations Biometry VB	Observations Age VB
	30/01/90	497			
	12/02	166			
	26/02	249			
	13/03	249			
	27/03	312	158	78	12
	12/04	166	166	138	
	25/04	264			16
Vilaine	11/05	303	304	101	16
	24/05	308			
	08/06	373			
	22/06	265			
	24/07	247			
	20/08	183			
	21/09	214	119	95	
	22/10	180			
	06/11	201	76	64	14
	05/12	196	190	190	
Loire	25/12/89	—			16
TOTAL		4 621	1 013	666	74

Table 2. Biometric observations of stage V_B glass eels from the Vilaine estuary in 1990.

Sampling date		Sept. 21	Nov. 6	Dec. 5	March 27	April 12	May 11
Sample size		95	64	190	78	138	101
	average	71.2	71.2	68.9	66.1	66.4	63.4
Length (mm)	SD	3.28	4.28	3.54	3.55	3.83	3.47
	SE	0.3	0.5	0.3	0.4	0.3	0.3
	average	25.8	29.6	33.7	28.6	27.7	25.6
Weight (10^{-2}g)	SD	4.92	6.12	5.72	5.20	5.18	5.36
	SE	0.5	0.8	0.4	0.6	0.4	0.5
	average	0.71	0.81	1.02	0.99	0.94	1.00
K	SD	0.09	0.09	0.09	0.10	0.10	0.12
	SE	0.01	0.01	0.01	0.01	0.01	0.01

Table 3. Comparison between mean values of length (L) and weight (W) of stage V_B glass eels from successive samples. (0 = $p > 0,05$; X = $0,01 < p < 0,05$; XX = $p < 0,01$)

		Sept. 21 L	Sept. 21 W	Nov. 6 L	Nov. 6 W	Dec. 5 L	Dec. 5 W	March 27 L	March 27 W	April 12 L	April 12 W	May 11 L	May 11 W
September 21	L	—											
	W												
November 6	L	0		—									
	W		XX										
December 5	L	XX		XX		—							
	W		XX		XX								
March 27	L	XX		XX		XX		—					
	W		XX		0		XX						
April 12	L	XX		XX		XX		0		—			
	W		XX		X		XX		0				
May 11	L	XX		XX		XX		XX		XX		—	
	W		0		XX		XX		XX		XX		

Table 4: Frequency distribution of the daily age of successive samples, (C . . leptocephalus zone, M . . metamorphosis zone, T . . total age).

Age (d)	November 6 n = 4 C	M	T	December 25 n = 16 C	M	T	March 27 n = 12 C	M	T	April 25 n = 16 C	M	T	May 11 n = 16 C	M	T
30											2			5	
40					5						5			2	
50		3			2			6			6			6	
60		5			6			4			3			3	
70		4			2			2							
80		2			1										
90															
100															
110													1		
120										1			2		
130										1			1		
140				1									1		
150				1			1			2					1
160	1						3			3			4		1
170				2			2			1					1
180	1			1			3			2		2	3		
190	2			1			2			2		1	1		2
200	5			6		1	1			3			3		1
210				2		1			2			2			3
220	3			1		2			3			4			
230	1			1		1			1			2			3
240	1		2			2			1			1			3
250			3			1			3			3			
260			1			3			1						1
270			2			1									
280			1			3						1			
290			2												
300			2												
310			1												
320						1									
Mean age	207.9	67.8	275.7	195.4	60.4	255.8	178.2	61.2	239.4	178.1	50.1	228.2	166.5	48.1	214.6
SD	20.3	8.6	23.4	24.2	11.8	30.5	15.2	8.2	17.5	27.7	8.1	26.8	30.2	9.4	31.2

Table 5: Mean values of glass eel length and of the otolith measurements (radius length, mean ages, mean growth rates)

L (mm): mean body length
Rt (μm): Otolith radius
Rm (μm): "leptocephalus" radius
Rt–Rm (μm): "metamorphosis" radius
L/T (mm.d^{-1}): mean somatic growth rate
Rt/T (μm.d^{-1}): mean otolith growth rate
Rm/C (μm.d^{-1}): "leptocephalus" otolith growth rate
(Rt–Rm)/M (μm.d^{-1}): "metamorphosis" otolith growth rate

		L	R_t	R_m	C	M	T	L/T	R_t/T	R_m/C	R_t–R_m/M
NOVEMBER	X	68,6	165,6	108,2	208	68	276	0,25	0,60	0,52	0,85
n = 14	SD	3,4	13,8	10,7	20	9	24	0,02	0,01	≈0,01	0,01
DECEMBER	X	66,6	156,4	99,6	195	61	256	0,26	0,61	0,51	0,94
n = 16	SD	3,4	19,3	12,4	24	12	31	0,03	0,02	≈0,01	0,01
MARCH	X	67,7	149,4	91,8	178	61	239	0,28	0,62	0,52	0,94
n = 12	SD	4,9	11,2	7,8	15	8	18	0,02	0,01	≈0,01	0,01
APRIL	X	66,1	146,9	99,7	178	50	228	0,29	0,65	0,56	0,94
n = 16	SD	5,1	15,4	15,5	28	8	27	0,04	0,02	≈0,01	0,01
MAY	X	62,8	129,9	85,0	167	48	215	0,30	0,61	0,51	0,94
n = 14	SD	3,6	17,1	15,4	30	9	31	0,06	0,02	≈0,01	0,01

Effect of provenance and density on growth and survival of glass eels *Anguilla anguilla (L.)* in mesocosm experiments

by

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ABSTRACT

Glass eels *A. anguilla* from the catch areas France, England and The Netherlands were stocked in drainable ponds with densities 1600 per hectare in three replicated mesocosm experiments with yearclasses 1987, 1988 and 1989. In another experiment glass eels from England were stocked at densities ranging from 160 to 1,600 per hectare. No additional food or fertilizers were supplied. The ponds were also stocked with mixed populations of bream *A. brama* and common carp *C. carpio*, 300-400 kg per hectare. The growth of the glass eels from different catch areas differed significantly in the provenance experiments 1988 and 1989. The absence of significance in the provenance experiment 1987 was probably due to the low numbers recaptured in some ponds in that year. The glass eels from France grew to larger mean sizes (20-24 cm) and higher mean body weights (15-23 g) after one summer than those from England (17-20 cm, 8-16 g). The glass eels from The Netherlands showed the lowest mean growth (14-18 cm, 4-8 g after one summer). Mean lengths and body weights of the 1+ eels after two summers (provenance experiment 1989 only) from France, England and The Netherlands were 30-35, 27-28, 25-27 cm and 40-77, 32-36, 24-31 g respectively.

In the density experiment there were no indications for reduced growth of the 0+ eels at higher densities.

The percentage apparent survival (recaptures at draining) of the glass eels after one summer was 20-43% (provenance experiment 1987), 57-90% (provenance 1988) and 47-88% (density experiment). The lower apparent survival in the provenance experiment 1987 was probably caused by the inappropriate draining techniques used. The apparent survival after two summers (provenance 1989 only) was 47-74%. There were no indications for differences in apparent survival of the glass eels from different catch areas but the glass eels showed a significant lower apparent survival at increasing densities.

INTRODUCTION

In many of the Dutch waterbodies the highly developed eel fisheries can only be maintained by stocking with glass eels or undersized yellow eels. Most, if not all, of the glass eels stocked are supplied by the Organisation for the Improvement of Inland Fisheries (OVB). The organisation acquires the glass eels from suppliers in France, England and The Netherlands. The recent rise in price of glass eels has induced a sharp decrease in the amount stocked in The Netherlands (Raat, 1990). In this connection the need for information on optimum stocking densities and on quality criteria for glass eels to be stocked has increased.

Maximum stocking rates in The Netherlands were 1,600 per hectare but these have generally not been applied on a yearly basis. Müller (1975) recommended stocking only 100-500 glass eels per hectare per year. Density dependency of the growth of yellow eels and glass eels in ponds under conditions resembling those in natural waterbodies was studied by Klein Breteler et al. (1990).

This paper presents the results of experiments on survival and growth of glass eels caught in different countries and on density-dependency of growth of 0+ eels.

MATERIALS AND METHODS

Provenance experiments and density experiment

Glass eels caught in France, England and The Netherlands were stocked at equal densities (1,600 per hectare) in six ponds in 1987, eight ponds in 1988 and eight ponds in 1989 (Table 1). Glass eels from one supply and catch area (England) were stocked at densities ranging from 160 to 1,600 per hectare in another six ponds in 1987.

By draining the ponds the eels were recaptured as 0+ eels in the autumn of 1987, 1988 and 1989. The yearclass 1989 was restocked as 0+ eels and was recaptured for the second time in 1990. Mixed cyprinid populations were also stocked in the ponds with biomasses and species compositions resembling those of natural fish populations in eutropic lakes.

Ponds

The ponds used were all drainable, 20 m wide and 1 m deep and ranged in surface area from 250 to 1,000 m^2 (Table 1).

The bottom consisted of fluviatile clay and peat, covered with a layer of sediment. During 1987, 1988 and 1989 submerged and floating vegetation were hardly present. In 1990 however the ponds B21, B22, B23, B24 and B26 were covered with up to 65-80% vegetation (mainly *Chara, Potamogeton, Elodea* and *Ranunculus* species and some filamentous green algae) while in the other ponds such vegetation was only present with less than 20% coverage.

The ponds had been in use for more than ten years. No fertilizers were applied during these years and no food was offered, neither to the eels nor to the other fish species present in the ponds, during the experiments. The ponds were filled within a month in advance of the first stockings of the glass eels. Draining of the ponds occurred in September (1988, 1990) or October-November (1987, 1989). After 6-9 drainings per pond in the provenance experiment in October 1987 the recaptures of the eels concerned were still not completed. In 1988 most, if not all, of the eels appeared to be recaptured by means of draining in combination with a rotenone (1 ppm) treatment (Klein Breteler *et al.,* 1990). All the ponds (those used in the provenance experiment and the density experiment in 1987 included) were treated therefore in this way in 1988 and 1990. In order to monitor the fish stocks during the provenance experiment 1989 the ponds were drained, but not treated with rotenone, in the autumn of 1989 and were refilled immediately after their first draining. The fish caught (part of the eel population and all of the other fish species) were returned to the ponds where they came from the following day.

Fish

Glass eels were obtained from suppliers in France (Dodat; River Gironde), England (British Channel Fisheries, Hancock, Cook; River Severn and surroundings) and The Netherlands (OVB; sluices Lake IJsselmeer). The glass eels used in the experiments were randomly sampled from large supplies (usually more than 100 kg). Following their acquisition the glass eels were stored in holding tanks for observation of mortalities for at least one day. No abnormal acute mortalities occurred.

In the provenance experiments 1987 and 1989 glass eels from France, England and The Netherlands were used, in 1988 they were from England and The Netherlands but not from France. The glass eels in the density experiment were caught in England. The periods of acquisition were late April 1987, early April-late May 1988 and mid January-early May 1989 (Table 1). The experiments were performed partly in duplicate in the provenance experiments 1987 and 1988 (Table 1). In 1989 the experiment with glass eels from France was in duplicate with one control pond and one treatment pond for both. Treatments were bathings with oxytetracycline 0.2 ppm for 72 hours.

Bream *Abramis brama* (L.) 15-33 cm forklength and carp *Cyprinus carpio* L. 20-36 cm were stocked in the ponds with cumulative biomasses of 300 kg per hectare (both provenance experiment 1987 and density experiment) and 400 kg per hectare (provenance experiments in 1988 and 1989) to reproduce conditions occurring in natural waterbodies in The Netherlands. In order to limit the recruitment of these cyprinids some pike fry *Esox lucius* L. were also stocked. The mean cumulative biomasses of these species ranged from 358 to 527 kg per hectare (Table 3).

The glass eels stocked and the yellow 0+ and 1+ eels harvested were anaesthetized (benzocain 50 mg/l), counted and measured to the nearest mm length. The glass eels were weighed to the nearest 0.01 gram in 1988 and 1989 (they were not weighed individually in 1987) after removal of excess water. The 0+ and 1+ eels were weighed to the nearest 0.1 gram. Pigmentation stages of the glass eels were determined according to Tesch (1983) in 1988 and 1989. Silvering of the 1+ eels (provenance experiment 1989 only) was noticed from external appearance.

Data

The mean lengths and body weights of the 0+ eels in the provenance experiment 1987 and in the density experiment were calculated from the eels recaptured in the year of stocking. 1+ eels recaptured in 1988, a consequence of the improper draining technique used in 1987, were not used for that purpose. The allometric conditions (Ricker, 1975) of the 0+ and 1+ eels were calculated as the percentage deviation of the actual weights of the eels from reference weights of eels of the same length caught in different waterbodies in The Netherlands. The reference length-weight relationship was $W = a.L^b$ with $a = 0.001066$ and $b = 3.133$ (Klein Breteler *et al.,* 1990). Fulton condition factors of glass eels were calculated as $1000.W.L^{-3}$.

The mean biomasses were calculated following Ricker (1975) using daily instantaneous mortality and growth rates. An estimate of the mean biomass of 0+ cyprinids was obtained by dividing the biomass at draining the ponds by two.

The apparent survival of eels was calculated from the numbers stocked and from the numbers recaptured, either as 0+ eels or as 1+ eels. The apparent survival is to be considered as a minimum estimate of the true survival of the glass eels in this study.

The data were statistically treated with the nonparametric Kruskall-Wallis analysis of variance, Mann-

Whitney U test, Chi-square analysis and Spearman rank correlation analysis. Pigmentation stages 5A-6B were transformed to scores 1-7 prior to the analyses. The statistical analyses were carried out per year.

RESULTS

Provenance 1987

The glass eels from the different catch areas were stocked at approximately the same date, the last decade in April (Table 1). They differed significantly ($p < 0.01$) in mean length. The Dutch glass eels were larger and had a higher body weight than the average English which were larger than the French.

After one growing season there were differences in mean lengths, body weights and allometric condition factors of 0+ eels from different ponds (Table 2). Statistically these differences between 0+ eels were inconclusive ($p > 0.05$), probably because of the low numbers of 0+ eels recaptured in 1987 (e.g. only 4 eels were recaptured from pond B13 in 1987). The French 0+ eels were larger and heavier than the average English eels which were larger than the Dutch eels, the opposite relational sequence as compared with the situation in the glass eel stage. The growth of the French glass eels appeared to be the highest. The results of the duplicates of the experiments with French glass eels (ponds B11 and B12, Table 1) with regard to growth were consistent in a qualitative sense: the 0+ eels in both ponds were on the average larger than the 0+ eels in the ponds stocked with English or Dutch glass eels (Table 2).

The allometric condition factor of the Dutch 0+ eels was lower than the condition factor of the English and French 0+ eels.

The apparent survival ranged from 20 to 45% (Table 2), much lower than the results of the provenance experiments 1988 and 1989 and of the density experiment in 1987 and also lower than the results of Klein Breteler *et al.* (1990). The many drawdowns of the water in these ponds at subsequent drainings, due to the improper draining technique used in the provenance experiment 1987, and the resulting increased risks of nocturnal predation, especially by herons *Ardea cinerea* L. probably negatively influenced the apparent survival of the eels in this experiment.

Provenance 1988

In 1988 the glass eels were obtained from England and The Netherlands but not from France (Table 1). The stocking date ranged from April 7 to May 20. The glass eels from the different catch areas differed significantly ($p < 0.0001$) in mean length, body weight, Fulton condition factor and pigmentation stage. The Dutch glass eels of May 20 were extremely small and had an extraordinarily low Fulton condition factor (Table 1). The mean body weights of the English were about twice as high as the mean body weight of the Dutch of May 20. The Dutch on May 11 also had a low condition and low body weight. The mean lengths of the Dutch on April 25 and May 11 were (approximately) equal to the mean lengths of the English (Table 1). Although statistically different, there were no pronounced differences in the stage of pigmentation of the glass eels from the different catch areas. Glass eels from England (April 7) were the least and those from England (April 20) and The Netherlands (May 11 and 20) were the most developed in pigmentation.

The 0+ eels were significantly different ($p < 0.0001$) with regard to length, body weight and allometric condition factor (Table 2). The mean lengths of the English ranged from 17.4 to 18.1 cm. The Dutch were on the average 13.8-14.6 cm. The body weights of the English 0+ were about twice as high as those of the Dutch glass eels by the end of their first growing season (mid September). Both the mean lengths and the mean body weights of the 0+ eels in mid September were significantly correlated ($p < 0.05$) with the mean body weights of the glass eels at stocking but not with the mean length at stocking. There seemed to be no relation between the developmental stage of pigmentation of the glass eels and the length or the body weight of the 0+ eels.

The results with the glass eels from England (April 7) indicated that the growth rates of these eels in length and in weight were equal in both these ponds (Table 2).

The apparent survival of the glass eels differed between the ponds ($p < 0.0001$) and was positively rank-correlated ($p< 0.01$) with the mean length (but not with the mean body weight or the mean Fulton condition factor: $p> 0.05$) at stocking.

Provenance 1989

The French glass eels were stocked in January and February and the English and Dutch in April and May 1989. The glass eels from the different catch areas differed significantly ($p < 0.0001$) in mean length, body weight, Fulton condition factor and pigmentation stage (Table 1). The French glass eels had the highest body weights and Fulton condition factors but were of intermediate length. English and Dutch specimens in mid April had the greatest lengths. English glass eels in early April and Dutch specimens in early May had the smallest size. Dutch early May specimens also had the lowest condition of all.

The English elvers in mid April and the Dutch elvers were (nearly) all in the 6A4 stage of pigmentation development (Table 1) and the French glass eels in January were all in the 5B stage. 5B-6A2 stages dominated in the French specimens in February and 6A2-6A4 stages in the English specimens in early April.

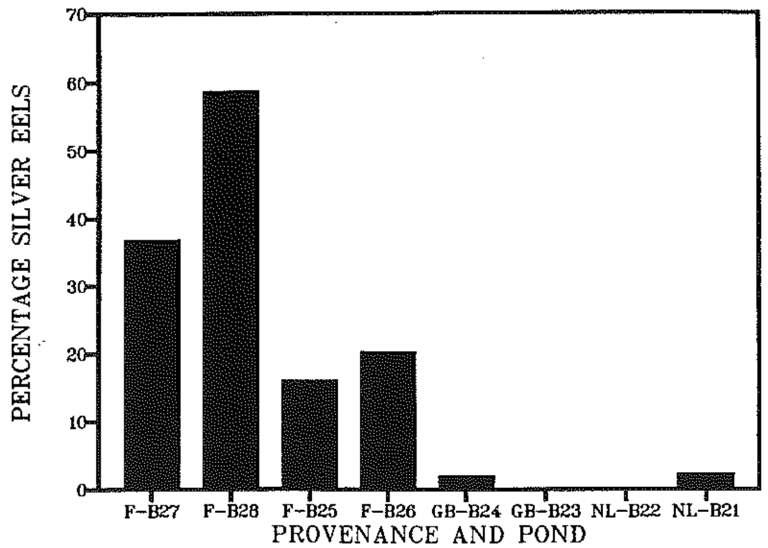

Figure 1. Percentage of silver eels in 1+ eel populations from different glass eel catch areas in the provenance experiment 1989-1990. F = France, GB = England, NL = The Netherlands. Numbers B21 to B28 refer to pond numbers.

Both the 0+ eels in 1989 and the 1+ eels in 1990 were significantly different ($p < 0.0001$) with regard to length, body weight and allometric condition factor (Table 2). The mean lengths of the French 0+ eels ranged from 21.4 to 23.5 cm, the English 0+ eels were on the average 18.3 and 19.2 cm long and the Dutch 0+ eels had a mean length of 16.2 and 16.8 cm. These differences in length between eels from different catch areas remained in the eels' second freshwater year when they reached sizes of 24.7 (provenance The Netherlands) to 35.3 (provenance France) cm mean length. The mean body weights ranged from 6.8 (Dutch) to 23.2 (French) g in October-November 1989 (0+ eels) and from 24.3 (Dutch) to 76.5 (French) g in September 1990 (1+ eels). Both the mean lengths and the mean body weights of the 0+ eels were significantly correlated ($p < 0.05$) with the mean body weights and with the mean Fulton condition factors of the glass eels at stocking but not with the mean length of the glass eels at stocking.

There was an inverse relation between the developmental stage of pigmentation of the glass eels and the length or the body weight of the 0+ eels.

The results of the experiment in ponds B25-B28 (Table 2) with oxytetracycline treatments of glass eels were inconclusive. No statistically significant effects ($p > 0.05$) were found on the growth of the treated glass eels from France.

The apparent survival of the glass eels up to the end of their second year differed between the ponds ($p < 0.05$) and was not rank-correlated ($p > 0.05$) with the mean length, body weight or Fulton condition factor at stocking. The highest percentage of recaptures (73.8%) occurred in the pond stocked with English glass eels in early April (B24).

The 1+ eels in the ponds B21-B28 differed with regard to the rate of silvering ($p < 0.0001$). Less than 5% of the Dutch and English eels, 15-20% of the French eels stocked in February and 36-59% of the French eels stocked in January were silver eels after their second freshwater year (Figure 1).

Stocking density

In October 1987 the 0+ eels ranged in length from 18.9 to 20.8 cm (Table 2) with no significant variation between ponds. The body weights ($p < 0.05$) and allometric condition factors ($p < 0.001$) differed significantly between the ponds.

The stocking density of the glass eels was not significantly correlated ($p > 0.05$) with the length or with the body weight of 0+ eels. The apparent survival varied from 46.9 to 87.5% and decreased with increasing stocking density ($p < 0.05$). The biomass of the 0+ eels increased with stocking density from 1.8 to 12.0 kg per hectare.

DISCUSSION

Growth of poikilotherms is largely determined by temperature, food consumed (quantity and quality), activity, size and genetic potentials. Density, temperature and food abundance are the primary factors in determining growth of eels (Tesch, 1983; Müller, 1975). Density was a constant in the provenance experiments in this study and did not influence the growth of the eels in the density experiment within the range of densities used. Temperature was excluded as a variable in this study because the analyses were made per year (equal temperatures for all lots of glass eels within a year) with similar results. Food abundance and composition were not measured but the ponds were identical and treated in the same way and we therefore assume that the forage basis was similar in the ponds within the years.

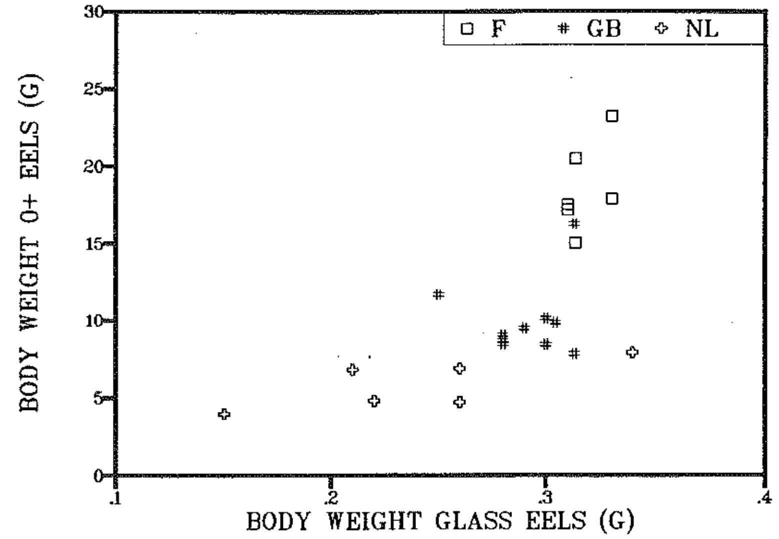

Figure 2. Scatter plot of body weights of glass eels from different catch areas and body weights of 0 eels recaptured. Pooled data from 1987-1989.

The peak supplies of glass eels from France generally occur in January and February. Glass eels from England usually are supplied in March and April. And in The Netherlands glass eels are caught mainly in April and May. In the provenance experiments in 1988 and 1989 there was the same trend in the dates of stocking of the glass eels. The French and English glass eels in the provenance experiments 1988 and 1989 might have been favoured therefore by the early stocking. Although the 1987 data with stockings of French, English and Dutch glass eels on approximately the same date showed a superior growth of the French eels, notwithstanding the smaller size and the lower body weights of these glass eels, the differences were not significant. There are thus only indications from these experiments for differences in growth potential of glass eels caught in different countries.

The mean body weights of the 0+ eels were related both to the body weights and to the catch areas of the glass eels (Figure 2). Bellini (1910) found and Wickins (1987) could not find differences in growth of glass eels with different body weights caught at the same localities. Growth and growth rate of fishes generally are affected by size (Ricker, 1975). The range of mean body weights of the Dutch glass eels was fairly large (Figure 2) but at increasing weights of these glass eels there was only a slight positive trend in the body weights of the Dutch 0+ eels. Hence, provenance of the glass eels seemed to determine growth more than body weight in these experiments. Unfortunately we did not carry out control experiments with French and English glass eels of a similar range of body weights as the Dutch glass eels. In a study of Boëtius & Boëtius (1989) mean body weights of glass eels from Denmark, from England and Scotland and from France were 0.12-0.22 g, 0.18-0.28 g and 0.26-0.32 g respectively. Body weights of French glass eels varied from 0.26-0.34 g through the year 1990 (Guerault *et al.,* 1991). The mean body weights of the Dutch, English and French glass eels in this experiment (Table 1) were, with one exception (Dutch glass eels in 1987: 0.34 g), slightly larger than those measured by Boëtius & Boëtius (1989) and the differences we observed in the glass eels with regard to body weight thus seem to be quite natural.

Heterogeneity in glass eels migrating inshore on the European Atlantic coast with regard to meristic characters was also found by Harding (1985) who concluded that the number of vertebrae of the glass eels is spatially and temporally not homogeneous, more vertebrae occurring in more southerly regions. We do not know whether these variations in meristic characters have a genetic base or are merely phenotypic.

Williams & Koehn (1984) reviewed the population genetics of North Atlantic eels, regarded the American and European forms as at least partly separate breeding populations and believed that the limited data available were against the recognition of the distinct species *A. anguilla* and *A. rostrata.* Avise *et al.* (1986) however showed a high distinction between the mitochondrial DNA of these species but could not detect differences in mtDNA of *A. rostrata* from different localities in North America or in mtDNA of *A. anguilla* from Ireland and England. Hence, up to now there seems to be no evidence for the existence of genetic strains in *A. anguilla* and our data seem to illustrate the diversifying selection of the environment.

A significant effect of stocking density on growth of the glass eels was not observed in this study. The growth of glass eels was shown to depend on the biomass of yellow eels (Klein Breteler *et al.,* 1990). Belpaire (1987) and Belpaire *et al.* (1989) demonstrated that the growth of glass eels in ponds was density dependent, by stocking glass eels with biomasses up to 204 kg per hectare. In this study we worked with biomasses less than 0.5 kg per hectare. Besides we also stocked cyprinids (300 kg per hectare) which may compete for the same resources (Lammens *et al.*, 1985). Belpaire focussed on alternatives for intensive eel culture. Our study was directed to an implementation of the results in the management of eel stocks. The results of this study show that it may be important at stocking glass eels to pay attention to the localities where the glass eels have been caught and also to body weights, more than to lengths, of the glass eels. When glass eels are stocked on a weight basis the effect of the body weight on growth will be partly compensated by the numbers stocked (higher body weight implies lower density but results in higher weights as 0+ eels). When they are stocked on a number basis one runs the risk of under-or overpopulation.

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Table 1. Data on stockings of glass eels from different catch areas in 1987, 1988 and 1989 and at different densities in 1987 (* = oxytetracycline treatment).

Pond -Area (m²)	Provenance	Date of stocking	Number /pond	length (cm)		Body weight (g)		Total weight (g)	Pigmentation (%)						Fultons' cond. fact.	
				Mean	Std	Mean	Std		5B	6A1	6A2	6A3	6A4	6B	Mean	Std
						1987 — PROVENANCE EXPERIMENT										
B11-250	F	21 Apr 87	40	7.0	.37	.31		12.5								
B12-250	F	21 Apr 87	40	7.0	.37	.31		12.5								
B16-250	GB	21 Apr 87	40	7.0	.40	.30		12.2								
B13-250	GB	21 Apr 87	40	7.1	.35	.31		12.5								
B14-250	GB	21 Apr 87	40	7.1	.35	.31		12.5								
B15-250	NL	27 Apr 87	40	7.2	.33	.34		13.6								
						1988 — PROVENANCE EXPERIMENT										
B23-500	GB	7 Apr 88	80	7.0	.39	.28	.06	22.4	13	22	35	20	11		.789	.090
B28-500	GB	7 Apr 88	80	7.0	.39	.28	.06	22.4	13	22	35	20	11		.789	.090
B24-500	GB	13 Apr 88	80	7.2	.34	.30	.06	24.0		17	30	28	24		.809	.079
B25-500	GB	19 Apr 88	80	7.1	.35	.28	.06	22.4		20	30	22	28		.802	.111
B22-500	GB	20 Apr 88	80	7.1	.35	.30	.05	24.0	2	2	15	22	59		.837	.053
B27-500	NL	25 Apr 88	80	7.1	.37	.26	.05	20.8		13	37	39	11		.743	.101
B43-1000	NL	11 May 88	160	7.1	.39	.22	.05	35.2		2	13	24	59	2	.630	.115
B44-1000	NL	20 May 88	160	6.7	.40	.15	.04	24.0			28	22	46	4	.541	.137
						1989 — PROVENANCE EXPERIMENT										
B27-500	F	13 Jan 89	80	7.0	.37	.33	.06	26.4	100						.971	.079
B28-500	F*	13 Jan 89	80	7.0	.37	.33	.06	26.4	100						.971	.079
B25-500	F	25 Feb 89	80	7.0	.36	.31	.05	24.8	26	39	22	9	4		.888	.077
B26-500	F*	25 Feb 89	80	7.0	.36	.31	.05	24.8	26	39	22	9	4		.888	.077
B24-500	GB	3 Apr 89	80	6.8	.33	.25	.05	20.0			37	33	30		.774	.081
B23-500	GB	12 Apr 89	80	7.2	.39	.29	.06	23.2			2	2	96		.784	.096
B22-500	NL	18 Apr 89	80	7.1	.31	.26	.04	20.8					100		.751	.086
B21-500	NL	2 May 89	80	6.8	.33	.21	.04	16.8					100		.688	.079
						1987 — DENSITY EXPERIMENT										
B22-500	GB	21 Apr 87	80	7.0	.40	.30		24.3								
B23-500	GB	21 Apr 87	64	7.0	.40	.30		19.5								
B24-500	GB	21 Apr 87	48	7.0	.40	.30		14.6								
B25-500	GB	21 Apr 87	32	7.0	.40	.30		9.7								
B26-500	GB	21 Apr 87	16	7.0	.40	.30		4.9								
B21-500	GB	21 Apr 87	8	7.0	.40	.30		2.4								

Table 2. Data on recaptures of eels stocked as glass eels from different catch areas and at different densities. Recaptures of 0⁺ eels in 1987, 1988 and 1989 and recaptures of 1 eels in 1990 (* = oxytetracycline treatment).

Pond -Area (m²)	Provenance	Date of first draining	Number /pond	Length (cm) Mean	Length (cm) Std	Body weight (g) Mean	Body weight (g) Std	Total weight (g)	Allometric condition Mean	Allometric condition Std	Apparent Survival (%)
				1987 — PROVENANCE EXPERIMENT							
B11-250	F	22 Oct 87	9	20.9	2.26	15.01	5.48	135.1	−1.3	8.3	22.5
B12-250	F	22 Oct 87	10	20.0	8.96	20.47	27.10	204.7	−6.2	12.1	25.0
B16-250	GB	20 Oct 87	16	18.6	2.36	9.83	4.38	134.0	−6.6	11.1	40.0
B13-250	GB	22 Oct 87	8	19.9	7.33	16.23	17.88	157.3	−5.5	4.3	20.0
B14-250	GB	22 Oct 87	8	17.3	2.09	7.82	2.41	129.8	−4.6	9.3	20.0
B15-250	NL	22 Oct 87	17	17.8	1.68	7.88	1.98	62.6	−13.1	5.8	42.5
				1988 — PROVENANCE EXPERIMENT							
B23-500	GB	14 Sep 88	69	17.8	2.20	9.03	3.24	623.2	−3.0	6.6	75.0
B28-500	GB	13 Sep 88	60	17.7	2.11	8.65	3.21	519.1	−3.6	7.8	62.5
B24-500	GB	14 Sep 88	72	18.1	2.74	10.11	4.99	728.1	−.7	9.9	90.0
B25-500	GB	13 Sep 88	62	17.4	2.07	8.46	2.94	524.6	−1.3	7.8	77.5
B22-500	GB	14 Sep 88	72	17.7	1.94	8.42	3.05	606.5	−6.0	7.9	86.3
B27-500	NL	13 Sep 88	50	14.6	1.67	4.72	1.88	236.2	−5.0	8.8	90.0
B43-1000	NL	12 Sep 88	101	14.6	1.58	4.79	1.90	484.2	−2.1	7.4	63.1
B44-1000	NL	12 Sep 88	90	13.8	1.53	3.96	1.37	356.7	−3.6	8.7	56.3
				1989 — PROVENANCE EXPERIMENT YEAR 1							
B27-500	F	2 Nov 89	12	23.5	3.31	23.19	9.89		3.8	4.1	
B28-500	F*	2 Nov 89	18	21.6	2.34	17.84	5.28		6.9	8.9	
B25-500	F	1 Nov 89	16	21.7	1.83	17.15	4.95		2.5	9.1	
B26-500	F*	1 Nov 89	13	21.4	2.39	17.46	6.64		5.7	8.5	
B24-500	GB	31 Oct 89	34	19.2	2.33	11.68	4.45		.8	7.9	
B23-500	GB	31 Oct 89	12	18.3	1.53	9.47	2.70		−4.4	8.0	
B22-500	NL	30 Oct 89	19	16.8	1.68	6.87	2.31		−10.1	7.0	
B21-500	NL	30 Oct 89	25	16.2	1.70	6.79	2.20		.6	8.9	
				1989 — PROVENANCE EXPERIMENT YEAR 2							
B27-500	F	20 Sep 90	41	35.3	4.43	76.52	25.70	3,137.2	−1.3	11.3	51.3
B28-500	F*	20 Sep 90	52	30.6	4.05	48.64	16.60	2,529.1	−2.6	13.3	65.0
B25-500	F	19 Sep 90	50	31.2	3.39	50.63	18.31	2,531.5	−5.1	10.3	62.5
B26-500	F*	19 Sep 90	38	29.9	3.11	40.09	12.33	1,523.6	−13.7	8.1	47.5
B24-500	GB	17 Sep 90	59	27.0	4.02	31.61	14.92	1,865.1	−9.7	8.4	73.8
B23-500	GB	17 Sep 90	55	28.4	2.98	35.75	11.48	1,966.4	−9.7	8.1	68.8
B22-500	NL	14 Sep 90	48	27.1	3.53	30.64	12.60	1,470.9	−10.6	9.0	60.0
B21-500	NL	14 Sep 90	49	24.7	3.97	24.28	14.09	1,189.5	−9.0	7.7	61.3
				1987 — DENSITY EXPERIMENT							
B22-500	GB	16 Oct 87	50	19.5	4.26	11.99	10.86	599.5	−10.3	10.1	62.5
B23-500	GB	19 Oct 87	30	20.8	3.38	15.07	7.35	452.1	−3.2	9.1	46.9
B24-500	GB	20 Oct 87	29	20.2	2.25	13.23	5.61	383.7	−3.5	9.9	60.4
B25-500	GB	20 Oct 87	22	20.6	2.41	13.09	4.87	288.0	−9.9	6.7	68.8
B26-500	GB	20 Oct 87	13	20.6	3.82	15.45	8.24	200.9	−1.5	10.8	81.3
B21-500	GB	19 Oct 87	6	18.9	5.15	12.97	8.66	90.8	.6	8.8	87.5

Table 3. Biomass of cyprinids and pike (kg per hectare) in the ponds during the provenance experiment in 1987-1990 and during the density experiment in 1987.

Species	Provenance								Density	
	1987		1988		1989		1990		1987	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Bream > 0+	178	14	215	21	349	29	272	56	172	13
Bream and carp 0+	38	26	12	12	60	22	8	13	22	14
Carp > 0+	148	11	126	26	115	18	144	45	164	5
Pike 0+			6	2	3	1				
Totals	364		359		527		423		358	

Age at recruitment of *A. anguilla* glass-eels on the eastern Atlantic coast as inferred from otolith increments

by

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INTRODUCTION

At the 1989 meeting of the EIFAC Working Party on Eel in Porto, it was agreed that ageing studies of newly arrived glass eels and elvers should be undertaken. The growth history, age and recruitment dynamics of glass eels and elvers were studied, through SEM examination of sagittal otoliths.

Glass eels were collected in France (Loire and Vilaine estuaries), in Morocco (Sebou estuary on Atlantic coast and Moulouya estuary in Mediterranean coast), in the Netherlands (Ijmuiden) and in Italy (Arno estuary). Glass-eels and elvers were killed by immersion in 70% alcohol. The total length was measured to the nearest mm. The pigmentation stage was determined according to Elie et al's distribution of pigment on the body surface (Elie et al., 1982). Sagittal otoliths were extracted, then embedded in epoxy resin (Promodentaire) and finely ground and polished until the otolith core was revealed. Polished otoliths were etched with E.D.T.A. and viewed under SEM (Hitachi S520). Otolith radius was measured and growth increment counted from SEM photographs at x 300, x 1500 and x 2000.

RESULTS AND DISCUSSION

Total lengths of glass eels and elvers upon arrival at the estuary varied between sites and seasons. The pigmentation stages of glass eels collected in earlier recruitments were dominated by stages VA and VB. Later in the season, pigmentation stages were dominated by VIA0 to VIA4.

The maximum otolith radius varied with pigmentation stage. The transition ring (Rt) was entirely deposited at stage VIA0. The central part of the ground otolith revealed an amorphous nucleus (18.5 ± 1.9 μm).

The nucleus was surrounded by the leptocephalus growth zone. The larvae generally grew fast during the early stage, then slowed between 40 to 110-120 days old then followed a fast growing period. The leptocephalus growth zone was surrounded by the metamorphosis zone which ended in the transition ring. Daily ages upon arrival on the coast and daily increments in the growth zone and in the metamorphosis zone were calculated. Variations between sampling stations are shown in the following Table.

	leptocephalus growth zone (μm) mean	std	metamorphosis zone (μm) mean	std	mean age (days)	mean daily increments growth zone	met. zone
Morocco	91.49	7.47	59.22	5.24	216	0.35	1.80
Bay of Biscay	94.88	14.03					
Loire	92.60	4.50	62.10	4.51	269	0.51	0.95
Vilaine	94.60	6.00	65.20	12.1	243	0.51	0.95
Severn	104.60	8.10	70.00	7.8	276		

Key conclusions from this study are as follows: fast growing larvae and slow growing larvae occurred. The time required for oceanic migration is shorter for the fast growing larvae than for the slow growing ones.

The transatlantic migration of eel larvae from the Sargasso Sea to the European coastal shelf requires less than one year.

Larval hatching dates, back calculated from their estimated ages indicate that the spawning season lasted from February-March to October.

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I would like to thank all those providing me samples of glass-eels:
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Elver migration in the River Corrib system, western Ireland

by

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ABSTRACT

Elver migrations were investigated in the western Irish River Corrib system in three successive years. Elvers were recorded as arriving on the seashore from November onwards and ascending into freshwater from April to June. Diel and lunar/tidal periodicities of migrations were observed. Mean lengths, weights and condition factors of the sampled elvers declined from November to June but the extent of elver pigmentation increased during the same period.

INTRODUCTION

Oceanographic conditions along the western shore of Ireland are greatly influenced by the effects of the North Atlantic Drift, which also contributes significantly to the temperate maritime climate of the island. The north easterly flow of this oceanic current is supposed to be a primary factor influencing the distribution of larval *Anguilla anguilla*, on the European coast.

Preliminary observations on elvers in the River Corrib were noted early in this century (Schmidt, 1906, Holt 1908). The present study was initiated to help establish the general migrational patterns of elvers colonising the Corrib catchment. A second objective was to evaluate the potential use of low-head elver traps (O'Leary, 1971), for monitoring elver recruitment to the population and as a source for stocking upstream reaches of the system.

Study area

The Corrib catchment area comprises about 3,000 km^2 and includes an extensive and varied network of riverine and lacustrine habitats of varying trophic status (Connolly, 1986). Lough Corrib is the largest lake in this system and is 6 km upstream from the sea. Water levels are regulated by means of a weir on the River Corrib at Galway. This weir is adjusted to maintain the water level at 8.3 m OD. Spring tides reach 6.1 m OD. The long term mean annual flow rate from the Corrib is 94.3 m^3/s, ranging from an August minimum of 35.53 m^3/s to a January maximum of 165.0 m^3/s, (information supplied by Office of Public Works, Dublin).

The Corrib estuary is 1 km long and runs due south into Galway Bay. In mild weather conditions the freshwater plume may extend 6 km west of the river mouth along the northern shore of the bay and fan out southerly to 5 km. There are many small rivers flowing into the bay but their discharge is of an order of magnitude less than that of the River Corrib. In this area spring and neap tides have mean ranges of 4.5m and 1.9m respectively. There are several canals and disused millraces which link the river to the estuary and circumvent the regulating weir. The flows through these are significant during periods of low discharge over the weir.

MATERIALS AND METHODS

An intertidal sampling site was established on the seashore, immediately east of where the Corrib estuary enters the bay, Fig. 1. The substrate consisted of earth fill overlain with stones ranging from 2mm to 400mm in diameter, which has been colonised by seaweek (*Fucus vesiculosus*). Elvers were collected in handnets during low tide by exposing their refugia underneath the stones and seaweed. Upstream of the saltwater wedge of the estuary, a low head elver brush trap was set on each bank in previously constructed elver passes at the regulating weir. The passes were covered by wire mesh to protect the migrating elvers from bird predation. The water flow through these traps was manually controlled by valves.

The sampling programme commenced with daily recordings of the catches from the brush traps from April to June 1980. Five subsamples (three in May and two in June), with specimen numbers ranging from 83 to 217, were taken to the laboratory. In 1981 monthly sampling commenced by collecting elvers on the seashore in January. By May it was apparent that the elvers had moved away from the shoreline as only 14 specimens were collected during a two hour sampling period. A sample was recorded in the brush traps later that month during the ascent into freshwater. No further samples were taken as the run was very small. Monitoring the 1982 elver ascent was initiated by inspecting the shoreline from October 1981 onwards.

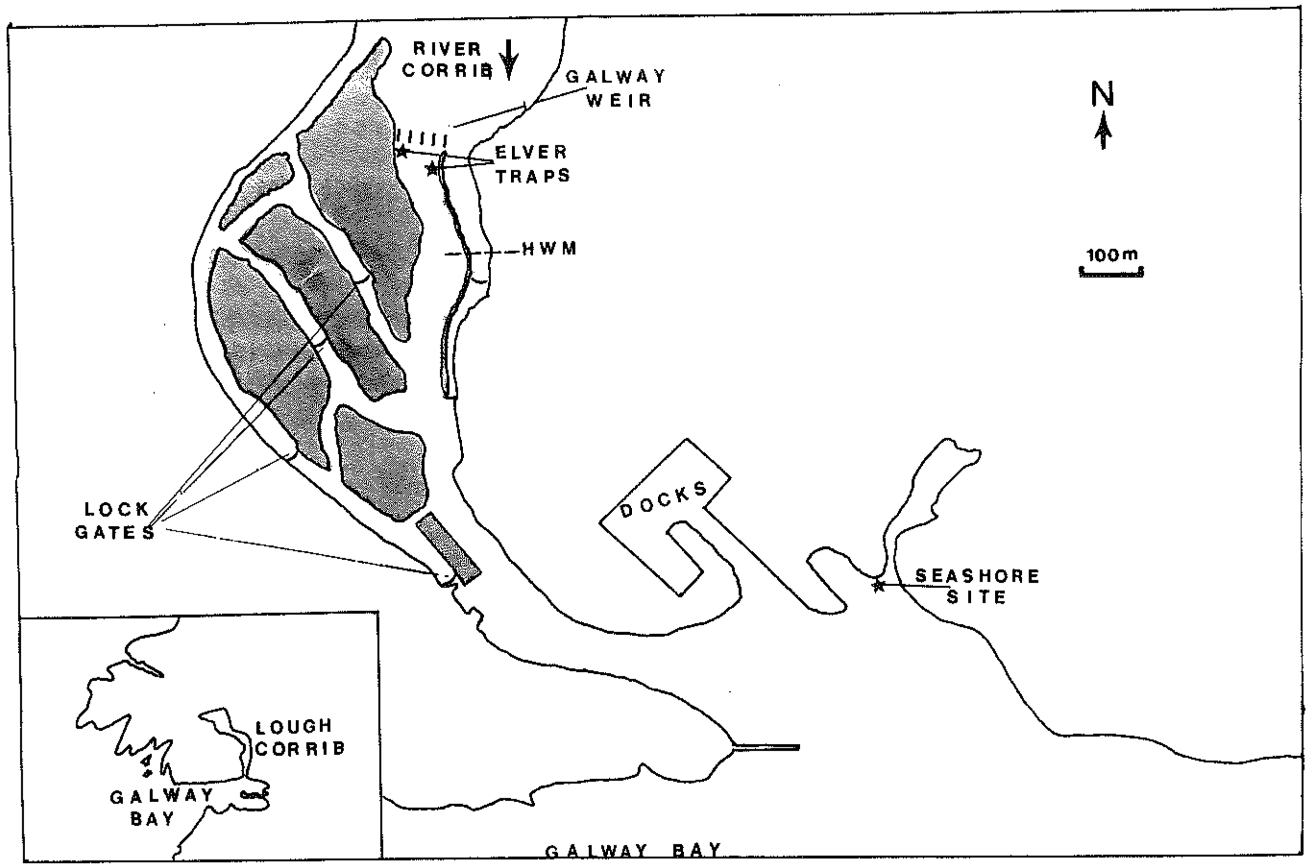

Figure 1. Map of Corrib estuary and canal network showing position of seashore sampling site and elver traps at Galway Weir with, inset, map of Galway Bay.

Elvers were first recorded in November and intertidal monthly samples continued until April when very few specimens were available. By this time they had commenced their ascent into freshwater and were recorded at the brush traps. All samples were sedated in chlorbutol (50mg/l), weighed and individuals assigned to millimetre size classes. The pigment developmental stages of the 1982 samples (November 1981 to June 1982) were classified according to criteria given by Tesch (1977).

RESULTS

Elver ascent patterns

The recorded daily catches at the brush traps from April to June in three successive years are shown in Fig. 2. The run commenced towards the end of April in 1980 and 1982. By mid-June less than 100 elvers were being trapped daily and the run had ceased by the end of the month. The traps remained in operation until the following September. The recorded catch in each year was 42.3 kg, 1.1kg and 11.7kg, respectively. The brush trap on the eastern side of the river always yielded a greater daily catch. Overall the numbers of elvers trapped were very low and in 1981 the elver run was virtually non existant. The riverine water temperature at the start of each annual elver run was 12.5°C, 11.5°C and, 11.8°C respectively, while the corresponding sea temperatures were 11.5°C, 11.0°C and, 12.5°C.

The daily catches were analysed in respect of time and height of high water mark (HWM), time after sunset and before sunrise. Nonparametric tests (Spearman rank correlation tests) revealed an inverse correlation ($r_s = -0.52$, < 0.001) between the daily catches in 1980 and the deviation in time of HWM from midnight. The nearest HWM was to midnight (irrespective of pre or post midnight) the greater the catch. Further examination of the tidal influence that year showed that there was a relationship between the size of the catch and the height of the tide seven days previously, Fig. 3. This relationship was very highly significant ($r_s = 0.46$, $p < 0.001$). In other words the higher HWM was the greater would be the catch seven nights later. The water flow over the regulating weir as calculated by the number of gates open showed little variation within seasons but varied between seasons.

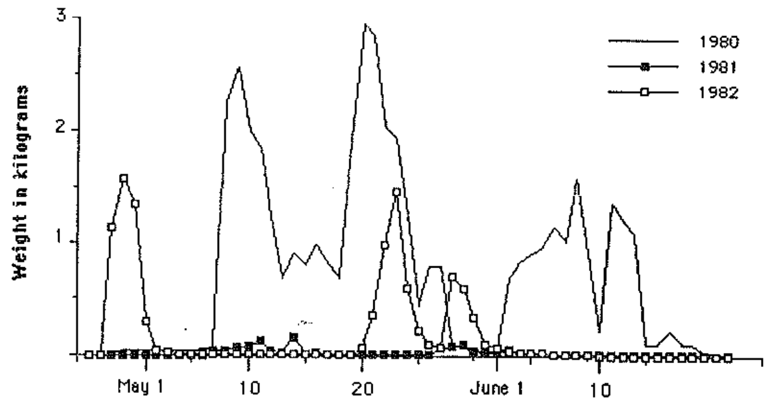

Figure 2. Daily elver catches in the low head brush traps at Galway Weir, from April to June, over three successive years.

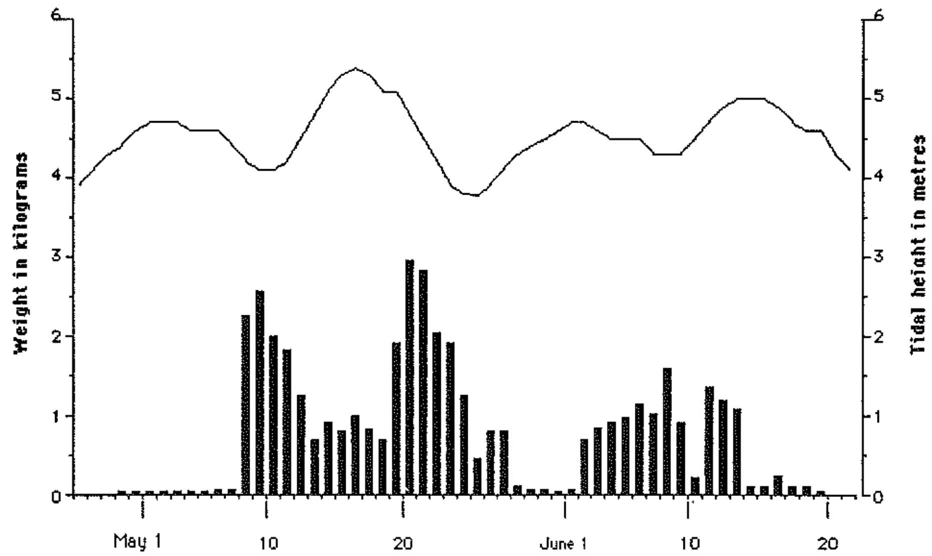

Figure 3. Daily elver catches (bar chart) in the low head brush traps at Galway Weir, and the local tidal height (line graph), April to June 1980.

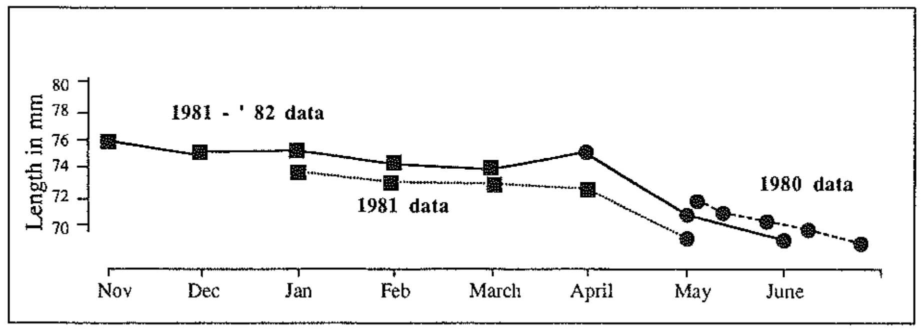

Figure 4. Mean lengths of elvers collected from the seashore (■) and taken from the brush traps at Galway Weir (●) over three successive years.

Elver size

The variations in length of elvers sampled in the three successive years are summarised in Table 1. There was a discontinuous reduction in the sample mean length within each year. Reductions in mean length throughout the three sampling periods are compared in Fig. 4. Differences between year classes were

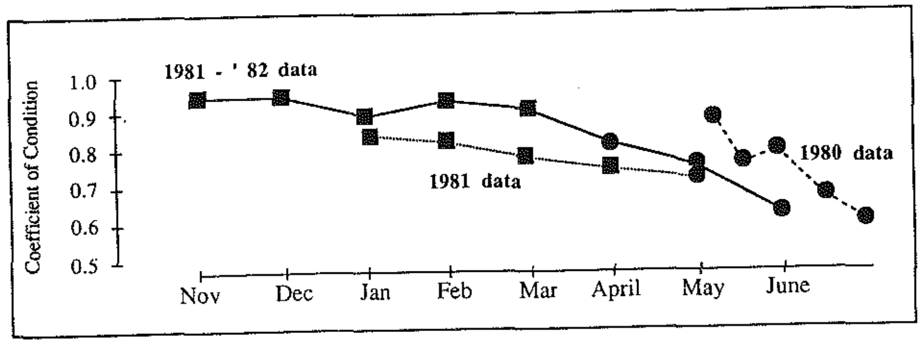

Figure 5. Variations in estimated condition factor of elvers collected from the seashore (■), and taken from the brush traps at Galway Weir (●) over three successive years.

maintained throughout the seasons. The decrease between successive shore samples was small in comparison to that recorded from the brush traps. In 1980 and 1982 the latter showed a 4mm (5.4%) and a 6.44mm (8.5%) reduction respectively in mean length over similar time spans. The decrease recorded from the seashore samples in 1981 and 1982 was less than 2mm (2.5%) in both years over a much longer period of time.

The seasonal decrease in mean length of elvers was associated with a reduction in condition factor ($K = W.10^3/L^3$, where W = body weight in g, and L = total length in cm), Fig. 5. There was an overall decrease in condition factor throughout each sampling season. The condition factors of elvers sampled on the shore in winter and spring months declined gradually. This trend was even more marked in the case of subsequent sets of elvers from the brush traps, Fig. 5. The highest condition factor value (0.93) was recorded in November elver samples from the seashore and the elvers trapped in June had the lowest value (0.63). The mean number of elvers to the kilogram in monthly samples increased during this period from 2,594 to 5,106.

Pigmentation

The degree to which elvers had developed pigmentation is shown in Table 2. There was an increase in the percentage of elvers that had progressively more advanced levels of pigment throughout the sampling period. The seashore series of samples showed that the degree of pigmentation was not determined by elver length. These results clearly show differences between elvers that colonised the sea shore in winter and those that ascended into freshwater the following summer.

DISCUSSION

After metamorphosis on the edges of the continental shelf unpigmented elvers migrate to the European coast, (Deelder, 1970). They are recorded on the Spanish and French coasts in September (Tesch 1977), in the plankton of the Skagerak and Kattegat from January (Lindquist, 1979), in the Helgoland Bight in February, (Tesch, 1971) and on the inner shores of Galway Bay in November. This time lag in colonisation may be a function of distance from the area of metamorphosis. Galway Bay is less than 250km from the 1,000m isobath and elvers swimming in oceanic waters at 7-8km/day (Tesch, 1977) could cover this distance in 32-36 days. The advantage of having a shorter active migration after metamorphosis is that energy is conserved and this seems to be reflected in their condition factor. The further east they travel the lower their condition factor. This ranges in elvers from 1.24 to 0.82 in the Portugese Rio Minho during November to March (Weber, 1986), 0.9 to 1.0 in elvers from the Sèvre Niortaise in France during March to June (Legault, 1987), and 0.57 to 0.41 at the Hojer Sluse in Denmark from April to June (Boëtius, 1976). The values recorded in the Corrib system reflect its geographical position in line with the above pattern. Elvers ascending into fresh water on the French Atlantic were recorded having an energy value twice that of those migrating into freshwater on the western coast of Denmark (Boëtius and Boëtius, 1989). It was suggested that the longer period spent at sea accounted for the lower energy value. Gandolfi *et al* (1984) noted the generally higher condition factor in more advanced pigmentation classes of elvers within samples from the River Arno.

The results from the present study indicate that elver recruitment to the Corrib catchment commenced with colonisation of the estuary in November, five months prior to migration upriver. During this period the seawater temperature dropped from 11.1°C at the beginning of November to a low of 3.2°C in January before rising again to 9.0°C by the beginning of April. The difficulty in obtaining samples from the seashore in April is interpreted as a movement away from the shoreline and into the flowing waters of the estuary. The ascent into freshwater through the brush traps commenced in April. Gascuel (1986) showed that unpigmented elvers utilised tidal currents to migrate up the estuary of the Sevre Niortaise from November to March. From April onwards when the water temperature reached 10°C they actively swam upstream. Weber (1986) investigating the Portugese Rio Minho recorded unpigmented and pigmented elvers all year

round with the latter absent during winter and most frequent in April. Maximum yields were recorded in February and March. Similar results were obtained by Charlon *et al* (1982) in the Adour basin area in France. Near the extreme of the species distribution in Norway, D'Ancona (1958) and Hvidsten (1985) recorded elvers in spring in the Imsa steam and migration upriver commenced in May with greatest catches recorded in June and July.

The data from this study revealed a more pronounced difference in morphometrics of elvers ascending the river through the brush traps than those colonising the seashore over a greater time span. The elver population on the shoreline is open, with possible continuous recruitment from November to March. The declining water temperatures during the winter would reduce their metabolic rate and their energy consumption. Before penetrating into freshwater they must first undergo certain physiological adjustments (Tesch 1977) and, when this is completed, environmental factors can influence the migration. Active swimming in the estuary with increasing summer temperatures would have a higher metabolic demand and consequent reduction in condition factor until elver feeding activity reverses this trend. Gandolfi *et al* (1984), suggested that temperature differences in excess of 3-4°C between riverine and saline waters will inhibit elver ascent. During the present study upsteam migration of elvers was observed to commence when river temperatures were greater than 11.0°C and the difference between it and the seawater temperature did not exceed 1.5°C. Hvidsten (1985) established a correlation between annual elver catches from the Imsa stream and the number of degree days above 11.0°C.

The moon through its tidal influences was suggested as having an influence on elver catches, (Deelder, 1960). Meyer and Kuhl (1952), reported that moon phase, air and weather conditions as well as hydrographic factors did not affect elver runs during their study at the German weir at Hebrum. Menzies (1936) noted that elver runs were coincident with a spring tide period, and Gandolfi *et al* (1984) established that tides had a clear cut effect on catches in the River Arno. Elver movements upstream in estuaries are thought to involve selected tidal stream transport mechanisms (McCleave and Kleckner 1982, Gascuel 1986, Legault 1987). Greater daily elver catches were recorded in the Galway brush traps when the time of high tide was close to midnight. In one season (1980) a highly significant correlation existed between the size of the catch and the height of the tide seven nights earlier. Under high river discharge conditions or at low water mark the water flow over the regulating weir would militate against rapid upsteam elver migration. It seems reasonable to conclude that spring and neap tides would assist in the migration through the estuary towards the upsteam limit of the saltwater wedge and that seven days may lapse before the elvers could reach the brush traps. While independent observations (McCarthy, unpublished data) have recorded elvers entering the lower reaches of the Galway canal network during high tide and sometimes in daylight hours, in excess of 96% of the catches at the brush traps were taken during the hours of darkness.

The results of the present study did not indicate that the elver brush traps as currently located on the Galway weir can provide sufficient material for stocking the upper reaches of the catchment. However, future work will be directed towards identifying more appropriate sampling methods and alternative trap sites in the river and canal network.

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Table 1. Lengths of elvers samples from the seashore and from the brushtraps at Galway Weir, during three successive years.

Date	Site	Number	Length (mm)		
			range	mean	sd
1980					
May 7	Trap	87	66-87	73.0	4.5
May 19	Trap	167	61-79	71.6	3.6
May 28	Trap	217	61-81	70.9	3.5
June 11	Trap	83	63-80	70.1	3.2
June 24	Trap	151	58-79	69.0	3.6
1981					
Jan 20	Seashore	100	68-84	74.1	3.4
Feb 19	Seashore	100	64-81	73.1	2.1
Mar 19	Seashore	100	66-80	73.1	2.9
Apr 6	Seashore	100	65-81	72.9	3.4
May 4	Trap	100	63-80	70.9	3.1
1982					
Nov 29	Seashore	100	65-84	75.6	3.6
Dec 28	Seashore	100	67-82	74.7	3.3
Jan 29	Seashore	100	67-82	75.0	3.0
Feb 28	Seashore	100	65-84	74.2	3.8
Mar 26	Seashore	100	65-85	73.8	3.5
Apr 30	Trap	100	65-82	74.9	3.5
May 28	Trap	100	63-78	70.4	3.3
June 14	Trap	100	60-77	68.5	3.3

Table 2. The number of elvers in each of eight pigmentation categories (Tesch 1977) in monthly samples collected on the seashore (Nov-Mar) and in the elver traps (Apr-June). The size ranges of elver samples, together with mean lengths and standard errors (in brackets) are also indicated. Sample size was 100 in all cases.

Pigment Stage	VA	VB	VIAI	VIAII	VIAIII	VIAIVA	VIAIVB	VIB
Nov	6 74-80 76.0 (2.8)	13 68-84 75.6 (3.5)	40 65-84 75.4 (4.4)	30 71-81 75.3 (2.5)	11 73-80 76.7 (2.1)			
Dec		8 71-81 76.1 (2.7)	48 67-82 74.9 (3.1)	44 67-82 74.3 (3.3)				
Jan		13 70-82 75.8 (3.3)	38 69-81 74.3 (2.6)	43 67-81 74.9 (3.0)	5 76-80 77.6 (1.6)			
Feb	1 — 74.0 (0)	11 68-79 73.0 (3.6)	26 68-84 74.7 (3.8)	41 65-83 74.2 (4.0)	21 67-83 74.2 (3.3)			
Mar		1 — 75.0 (0)	16 67-78 73.6 (2.6)	46 66-84 73.9 (3.8)	38 67-81 73.8 (3.7)			
Apr						22 68-80 74.5 (22)	72 65-82 75.0 (3.3)	6 66-81 73.8 (4.5)
May						3 68-74 70.6 (2.4)	90 63-78 70.3 (3.3)	7 66-75 71.7 (2.7)
June						3 65-71 68.3 (2.4)	61 61-76 68.7 (3.2)	36 60-74 68.1 (3.2)

Catches of *Anguilla anguilla* elver on the Atlantic coast of Europe 1989-1990

by

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ABSTRACT

Catch data of elvers from 12 reporting stations for 1989 and 1990 are compared with the annual mean for the ten year period 1981-1990. All catches in 1989 were below the mean as were all but 4 in 1990. Some local improvements were shown in 1990 but the means for the 1980's were substantially lower than those observed from 1960 to 1980.

INTRODUCTION

The Working Party on Eel of the European Inland Fisheries Advisory Commission has been engaged since 1979 in collating observations on the capture of young eels in European coastal waters. Details of reports up to 1988 are given in Moriarty (1990). These showed, with few exceptions, a period of abundance lasting about 20 years between 1959 and 1980 followed by a severe decline in catches and abundance indices throughout the 1980's. The figures given all refer to glass eels or to pigmented eels of less than 70mm length assumed to have been in estuarine or fresh water for less than one year. This note updates the 1990 database and makes tentative comments on the significance of the observations.

RESULTS AND DISCUSSION

Information received is presented in Table 1 together with data from 1981 onwards. Catches in 1989 were all lower than the 10-year mean and in the cases of Vidaa, Shannon, Ems, Den-Oever, Loire and Vilaine the lowest for the whole period. A slight increase was recorded for 1990 for Imsa, Viskan, all three Irish stations and Den Oever. The catch of 200kg in the Yser in Belgium was the highest in the decade.

The overall picture for 1989 and 1990 was of even lower catches than earlier in the 1980's. The decline of the 1980's has evidently continued into the 1990's and a period of ten years of poor catches and low recruitment indices has now been observed. The longer term figures presented in Moriarty (1990) show a period of good catches extending over 25 years from 1955. Only the River Loire provides catch data for the quarter of a century from 1931 to 1955. Records at Den Oever began in 1938. It is interesting that low values were the rule between 1931 and 1955. However, in the case of the Loire, it is not certain that a comparable effort was involved.

Many factors which could influence the records, for example water temperature, river flow and methods of data collection have seldom been fully considered. Allowing for such variations there is no good reason to doubt that by comparison with the 1960's and 1970's the numbers of elvers entering Atlantic European waters have been very small. Furthermore, the virtual failure of migration in rivers such as the Ems (Table 1) is very likely to be reflected in a reduction of the stocks of yellow eel. In other cases, the effect of poor recruitment cannot yet be quantified. We have yet to determine the relationship between numbers of glass eel entering a given estuary and numbers leaving the estuary for fresh water. Another potentially important factor is the rate of natural mortality in estuaries. For example, the effect of the capture of many tonnes of elvers for human consumption is unknown. It is possible that natural mortality is so high that this fishing mortality has no effect on the size of the populations of yellow eels in the river system. Equally, it is possible that the high fishing mortality leads to ultimate reduction of the breeding stock.

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Table 1. Catches of 0^+ eels by weight, by index to zero mean for Den Oever (1938-1985), larval catch per hour for Bay of Biscay and CPUE of professional fishery for Vilaine and Loire.

	Imsa kg	Vidaa kg	Viskan kg	Bann t	Erne t	Shannon t	Ems t	Den-Oever index	Yser kg	Loire t	Minho t	Biscay index	Vilaine cpue	Loire cpue
1981		226	513	4.5	2.8	2.1	.96	.4	74	284	54.2	6	16.1	5.7
1982		490	380	5.7	4.5	3.1	.67	−0.1	138	266	16.4	6	13.6	8.5
1983	7	662	308	.4	.7	.6	.12	−0.5	10	276	30.4	6	9.8	5.1
1984	3	123	21	2.3	1.1	.5	.35	−0.4	6	168	31.3	2	9.0	6.7
1985		13	200	.8	.4	1.1	.25	−0.6	13	159	20.7	2	8.2	6.2
1986		123	151	2.7	.7	.9	.11	−0.7	26	137	12.5	3	8.0	6.4
1987	2	341	146	2.5	2.3	1.6	.01	−0.5	33	93	8.2	4	8.3	5.0
1988	7	141	92	3.9	3.0	.1	.02	0.4	48	138	8.0	5	9.0	5.2
1989	4	9	32	2.3	1.8	.1	.01	−0.8	30	61	8.6	2	4.3	3.9
1990	13	5	42	3.4	2.4	.5	.01	−0.4	200	76	5.6	—	4.4	3.6
Mean	6	213	188	2.8	2.0	1.1	.25	−0.4	57	165	14.7	3	9.1	5.6

Growth studies on monthly captured glass eels from the Rio Minho in two recirculation systems

by

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ABSTRACT

The rearing success of monthly captured glass eels *Anguilla anguilla* (L.) was examined over a period of 70 days in individual & combined recirculation systems (IRS & CRS).

The highest growth rate per feeding day (2.9%) and the lowest final mortality (2.4%) were obtained by October glass eels caught in the estuary.

Generally the individuals from the other months revealed better results in the IRS than in the CRS. *Ichthyophthirius* infections in both systems were responsible for negative growth rates and final mortalities up to 100% among the glass eels from January and April.

INTRODUCTION

The initial phase of eel culture involves several problems concerning adaptation to artificial conditions and food. Success at this stage is dependent on the quality of the glass eels and is therefore the determinant for good final results.

For this reason it is important to establish whether the quality of glass eels changes significantly during the fishing season.

An initial approach to this question based on experiments with glass eels from the Rio Minho (Weber & Antunes 1990) showed the need for further experiments.

Following that demand, the aim of this study was to determine the monthly variations in quality. The glass eels of two different catch sites were compared and reared in two recirculation systems.

MATERIAL AND METHODS

The glass eels were caught once a month in the international Rio Minho during the official fishing season between October 1989 and April 1990, according to the method described by Weber (1986).

Depending on weather conditions, the fishery took place around new moon at two different sites, in the estuary and 20km upstream.

The two types of recirculation systems were applied for the rearing experiments. The individual recirculation systems (IRS, Fig. 1) were composed of 21-litre silos, designed according to Kuhlmann & Koops 1981, each one connected to its own filter.

In the combined recirculation systems (CRS, Fig. 2) designed by Weber & Antunes (1990), six identical silos were linked to one filter unit.

Both filters combined biofiltration and hydroponic cultures. An unit of the IRS consisted of a 40-litre cylinder filled up with plastic "hedgehogs" and planted with *Ipomoea batatas, Tradescantia sp.* and *Cyperus papyrus*. The water circulation was provided by "air-lifts" and adjusted to 4.0 l/min, resulting in 11 changes per hour. The water was heated by 50 W thermostats to obtain a temperature above 20°C.

In the CRS, the water left the six silos through a 22-litre trickling filter planted with *Monstera deliciosa* and passed through two biofilters of 95-litre each, the first occupied by the roots of the hydroponic culture and the second filled with plastic "hedgehogs". An Eheim pump elevated the filtered water to the silos, resulting in a flow rate of 1.8 l/min and 5 changes per hour per silo. The water was heated by two 200 W thermostats.

An emergency system, composed of a car battery (12 V DC) and a compressor, provided air for all silos (CRS & IRS) during failures of the main electrical supply (220 V AC).

The silos were cleaned by draining water from the bottom to remove the waste and about 10% of the total water volume was replaced daily (IRS: 6 l per unit; CRS: 30 l).

Every day dead individuals were counted and weighed and the water temperature was recorded. Other parameters such as O_2, NO_3, NO_2, and NH_4 were checked weekly by using Merck test kits (NO_2: 14774,

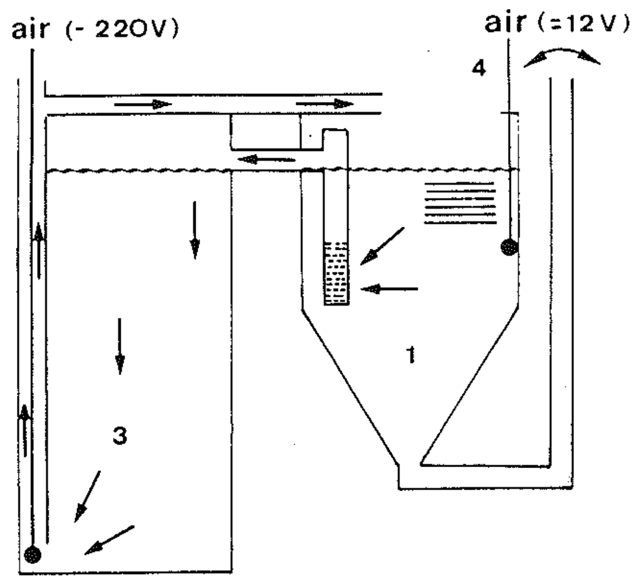

Figure 1. Individual recirculation system (IRS), (1- silo, 3- biofilter, 4- emergency system).

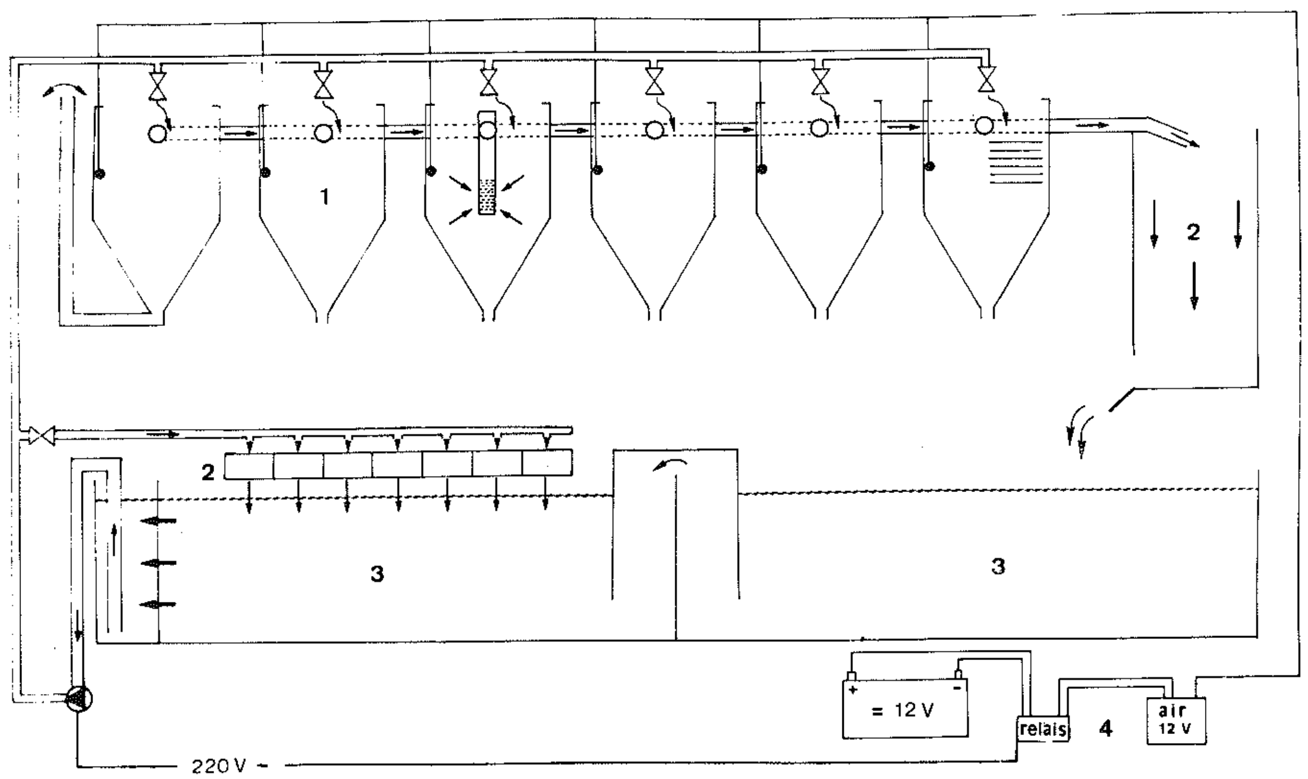

Figure 2. Combined recirculation system (CRS), (2- trickling filter with hydroponic culture).

NH_4:14750, O_2:11107, NO_3:10020). A microprocessor with automatic calibration (WTW 196) was used for pH measurements.

Both systems were stocked monthly with glass eels from the estuary and the upsteam catch site when possible. Initial densities varied from 5.8 to 10.6 g/l.

After three days of adaptation the individuals were fed with frozen cod roe once a day, offered over a period of 24 hours and 7 days per week. The daily ration of food varied between 1 and 7.5% of the body weight. Uneaten food, retained by the 50 μ sieve, was removed from the bottom of each silo the next day and weighed.

At the start and the end of the culture periods, generally after 70 days, samples of 100 individuals were

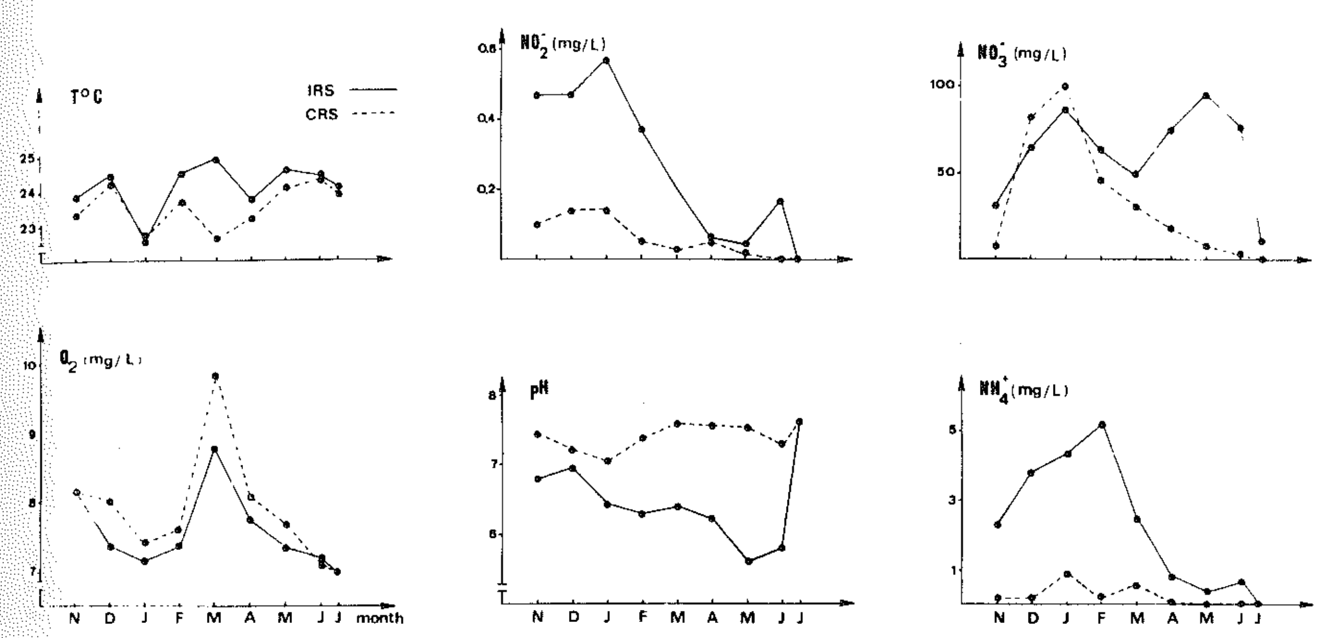

Figure 3. Water quality in the individual and combined recirculation systems (monthly means).

taken by flushing the silo. Individuals were anaesthetized with ethylene glycol monophenil ether before measurements of weight and length.

Malachite green (0.5ppm) was applied when any sign of *Ichthyophthirius* infections appeared.

Three fundamental parameters of quality were considered for the estimation of the rearing success:

—final mortality

—growth rate per feeding day (%) = $(\ln Wt - \ln Wi) \times 100/t$

—food consumption rate (%) = $\dfrac{Fc \times 100}{0.5 \times (Wt + Wi) \times t}$

Wt — final weight, Wi — initial weight, t — feeding days, Fc— food consumed (wet weight).

RESULTS

Comparing the two systems, the highest growth rates per feeding day and the lowest final mortalities were recorded from the individual recirculation systems.

A clear difference between the results obtained in the IRS and CRS could be demonstrated by nearly all groups of glass eels except by those from January and April which lost weight and reached final mortalities up to 100% mainly due to persistent *Ichthyophthirius* infections (Table 1-4).

The water quality was superior in the CRS. Peaks of NH_4 (monthly max. = 5.2 mg/l, mean 2.4 mg/l) and NO_2 (monthly max. = 0.57 mg/l, mean = 0.3 mg/l) were found in the IRS silos. The pH was lightly acid (mean = 6.4) in the IRS while it was nearly basic in the CRS (mean = 7.42), where the values of dissolved oxygen were greater (Fig. 3 & Table 5).

Glass eels from October showed the best results in both systems, with the highest growth rate of 2.9% per feeding day at a food consumption rate of 7.8% and the lowest final mortality of 2.4%.

The individuals caught in November and February still produced good weight increases, especially in the IRS (1.8%-2.6%) The glass eels reared in the CRS from December, January, March and April presented very high mortalities and in half the cases negative groth rates. The groups reared in the IRS from December and March, showed a quite reasonable growth (1.7%-2.0%).

The individuals from February revealed in the IRS a growth rate of 2.6% at a feeding rate of 7.7% based on data records from dead glass eels after a rearing period of 31 days due to a failure of water circulation.

Bad weather conditions prevented fishing at the upstream site in December, January and February. The glass eels from the remaining months showed different growth rates in relation to the catch site. The October group, reared in the IRS, gave 2.9% for the estuary and 2.1% for the upstream catch site. Only the individuals from March presented similar results (1.9% and 2.0%) comparing the two catch sites.

The poor results, generally found in the CRS, were due to *Ichthyophthirius* infections, first noticed among glass eels from October and then more intensively after introduction of the December group from the estuary.

The initial mortality due to fishing procedure, handling and transport of the glass eels did not change very much within the groups (mean = 6%) except for those individuals captured in the estuary in October (mean = 64%).

DISCUSSION

The design of the individual recirculation systems brought some advantages in comparison to the combined recirculation system. Temperature control in the beginning of the experiments made a gradual adaptation possible, which might explain the lower initial mortality of glass eels of the same origin in the IRS. It also allowed individual treatment for each silo and avoided the risk of contamination between the different groups of glass eels, which probably had happened in the CRS.

The water quality in the CRS was reasonable, due to an active biofilter and a well developed hydroponic culture of *Monstera deliciosa*, although the water exchange rate was lower and the total animal load increased every month by introducing new groups of glass eels. The water quality in the IRS showed higher concentrations of nitrogen compounds because the hydroponics were only partially and the biofilters not at all developed at the start of the experiments. Anyhow, the association of biofiltration and hydroponics seems to have a positive effect on the stability of water quality in recirculation systems (Lewis et al. 1978, Weber 1984, Weber & Antunes 1990). The evaluation of the plant biomass produced might also give an idea of the success of this association.

Cod roe is considered to be one of the best initial feeds for glass eels and was used during all experiments (Tautenhahn 1989). The adaptation to this diet within three days was considered to be fast and a relationship to higher mortalities could not be established, although some dead individuals displayed "waterbellies" as recorded by Kamstra & Heinsbroek 1989.

Good rearing success was obtained in the IRS systems with glass eels from the first two months of the fishing season. Growth of the following groups decreased but individuals from February, caught in the estuary, also revealed good results (2.6%). A similar situation has been recorded by Weber & Antunes 1990.

The October and November glass eels from the estuary and to some extent from April, grew better in the IRS units than those from upsteam. Due to bad weather conditions fishing was not possible for three months at the upstream site. Because of this lack of data any influence of the catch site on the rearing success could not be surely proved yet, but will be subject of further experiments.

In general the IRS design guaranteed better maintenance of the ongrowing glass eels. Because of persistent *Ichthyophthirius* infections the growth in the CRS was poor, with the exception of the glass eels from October and November.

The higher mortalities in the CRS following introduction of the December group might also have been caused by the build-up of an ectoparasitic fauna in the system which became difficult to control. In the case of the IRS, these infections caused very high mortalities among the glass eels from January and April.

The frequency of malachite treatments did not interfere negatively with the biofiltration capacity but were considered to be an additional factor of stress.

Compared with results in the literature, the growth and food consumption rates as well as the final mortalities of the glass eels reared in the IRS were reasonable except for those from January and April (Kamstra & Heinsbroek 1989, Kuhlmann & Koops 1981, Weber & Antunes 1990).

The variation of the rearing success among the glass eel groups and the better performance from certain months point towards the choice of two "ideal fishing seasons" for culture purposes between October-November and February-March. Further studies will try to prove this.

Anyhow, the quality of glass eels should not only be based upon the parameters applied in this study. The energetic and chemical compositions of the body tissues at the start and the end of each experiment as well as resistence to diseases, although not directly measurable, would also be important information to obtain.

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Table 1. Culture results in the IRS with glass eels from the estuary.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Feeding days	67	67	67	40	31	65	65
initial average							
weight (g)	0.32	0.32	0.32	0.3	0.28	0.28	0.3
length (cm)	6.90	6.92	6.97	6.79	6.84	6.79	7.16
final average							
weight (g)	2.17	1.52	0.98	0.28	0.64	0.94	0.37
length (cm)	11.0	10.27	9.36	6.35	8.05	9.37	7.03
daily growth rate per feeding day (%)	2.9	2.3	1.7	−0.2	2.6	1.9	0.3
food consumption rate per feeding day (%)	7.8	9.2	9.2	6.9	7.7	6.2	6.4
initial mortality (transport) (%)	66.7	7.1	8.8	1.0	5.3	1.0	7.5
final mortality (system) (%)	2.4	10.1	6.6	99.0	7.1	3.4	91.6

Table 2. Culture results in the IRS with glass eels from the upsteam catch site.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Feeding days	67	65				65	56
initial average							
weight (g)	0.33	0.32				0.27	0.25
length (cm)	6.86	6.86				6.94	6.98
final average							
weight (g)	1.34	1.05				0.96	0.13
length (cm)	9.26	9.07				9.10	6.35
daily growth rate per feeding day (%)	2.1	1.8				2.0	−1.2
food consumption rate per feeding day (%)	7.1	9.0				7.4	4.1
initial mortality (transport) (%)	13.6	8.6				3.0	1.4
final mortality (system) (%)	3.6	8.2				6.8	99.8

Table 3. Culture results in the CRS with glass eels from the estuary.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Feeding days	64	61	61	62	29	58	64
initial average							
weight (g)	0.32	0.32	0.32	0.3	0.28	0.28	0.3
length (cm)	6.90	6.92	6.97	6.79	6.84	6.79	7.16
final average							
weight (g)	0.9	0.9	0.45	0.38	0.34	0.09	0.29
length (cm)	9.46	8.57	7.13	7.01	7.03	5.90	6.83
daily growth rate per feeding day (%)	1.6	1.7	0.6	0.4	0.7	−2.0	−0.05
food consumption rate per feeding day (%)	6.9	10.9	3.8	4.6	2.4	0.7	0.7
initial mortality (transport) (%)	60.7	12.7	10.5	2.4	4.0	3.2	11.3
final mortality (system) (%)	11.5	23.9	92.9	96.8	90.6	99.8	99.3

Table 4 Culture results in the CRS with glass eels from the upsteam catch site.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Feeding days	64	61				58	49
initial average							
weight (g)	0.33	0.32				0.27	0.25
length (cm)	6.86	6.86				6.94	6.98
final average							
weight (g)	1.06	0.91				0.34	0.16
length (cm)	9.48	8.77				6.90	6.40
daily growth rate per feeding day (%)	1.8	1.7				0.4	−0.9
food consumption rate per feeding day (%)	7.1	7.1				1.2	1.1
initial mortality (transport) (%)	28.8	6.8				4.1	8.8
final mortality (system) (%)	8.0	37.4				99.6	99.8

Table 5. Quality of the recirculated water in IRS and CRS. $\bar{x}$ = weekly mean (n = 35); chemical concentrations in mg/l.

	IRS				CRS			
	$\bar{x}$	sd	min	max	$\bar{x}$	sd	min	max
T°C	24.1	1.0	21.4	25.5	23.5	0.84	21.4	24.9
NH4	2.4	2.0	0.0	5.4	0.25	0.57	0.0	3.0
NO2	0.3	0.3	0.03	1.4	0.06	0.08	0.0	0.25
NO3	64.0	31.6	5.0	108.0	34.5	39.7	0.0	100.0
pH	6.4	0.7	4.8	7.5	7.42	0.28	6.8	8.0
02	7.6	0.98	5.1	10.0	7.9	1.3	4.5	11.5

Age and birth date of elvers collected in Moorea (French Polynesia)

by

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Three species of *Anguilla* are found in French Polynesia: *A. marmorata, A. megastoma* and *A. obscura* (Marquet, 1987).

This paper dealt with the morphometric parameters and the age of *A. marmorata* elvers (stage VI B) collected on March 1989 in Moorea Island. Their growth history and their time of recruitment were analysed using otolith daily increments.

These elvers were shorter (TL from 4.3 to 5.7 cm) than those of *A. Anguilla* (TL from 6 to 8 cm).

The mean age of the elvers read through the daily increments from the nucleus to the transitional ring was 172 days. The specimens collected in March therefore were presumably spawned in the previous September. Recruitment of glass eels had begun in January.

Larval life duration (6 months) is rather short when compared to that of *A. anguilla* (8 to 11 months). The spawning site of the species should be not far from Moorea Island.

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Influence of some abiotic factors on the abundance of glass eel *Anguilla anguilla* (L.) in the estuary of the River Loire, France

by

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Daily total catch and catch-per-unit-effort data were collected for five fishing seasons (1984-8) from the outer estuary and riverine zones of the Loire elver fishery. Relationships to tides, river discharge and water temperatures were analysed on intra- and inter-annual bases via time-series analyses.

On an intra-annual basis, a fundamental 15 day tidal cycle component was identified, plus a seasonal trend of increasing numbers from December to February-March. On an inter-annual basis, elimination of tidal effects left a seasonal component of 150 days, describing the time-course of the migration of glass eels from outer estuary to riverine sites. Water temperature (critical value 4°C) was an important remaining trend influencing the timing of migration. These time-series data relationships could be used as a basis to develop a long-term abundance index for glass eels.

Food and feeding activity of glass eel *Anguilla anguilla* (L.) stocked in earthen ponds

by

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ABSTRACT

Two small earthen ponds (surface 0.125 ha) were stocked with glass eel during spring 1989. The stomach content of these eels, sampled at regular intervals during the year, was analysed both qualitatively and quantitatively. The stomach content turned out to be very diverse and season dependent. Variations in the benthos communities in the ponds are reflected in the species composition of the food. Although these young eels are mainly benthivorous, Cladocera can frequently be observed in the stomachs. The daily consumption rate is calculated and on the basis of stomach analyses of eels sampled at 3h intervals a digestion model for a 24h cycle is presented.

INTRODUCTION

The many studies which have been undertaken to assess growth of the European eel under natural conditions have resulted in quite diverse observations and interpretations. Growth potential of eels under natural circumstances (as well as under intensive aquaculture conditions) turns out to be extremely diverse, as growth is influenced by a multitude of ecological factors which interact in many ways (Tesch, 1977).

Simplifying experimental models by e.g. following eel populations of one age group in restricted environments such as earthen ponds gives conclusive results and allows some extrapolations to the natural conditions. However, one has to bear in mind that such habitats, although more or less similar to natural conditions, are clearly different from natural waterbodies. Ponds normally do not permit escapement and migration is impossible. If the ponds are stocked only with glass eel, the absence of prey and predator fish will influence this monospecific fish community.

As in most experimental conditions densities are higher than in nature, these high densities will have their impacts on the fish population such as increased predation by birds, or, more importantly, infection pressure by pathogens (bacteria, fungi, parasites). Finally, due to these higher densities, food availability and intraspecific competition will play predominant roles in this ecosystem.

Previous experiments with glass eel stocked in earthen ponds showed that several factors may influence considerably the growth of the eels (and hence fish production in the ponds). Some of these factors were stocking density, pathology, origin of the glass eel and water quality (Belpaire et al., 1989). However, obviously the most important parameters affecting eel growth in earthen ponds are feeding activity and food availability. Studies on food and feeding activity of glass eel or small eels (<18cm) are scarce. De Nie (1987) studied feeding regimes of eels mainly belonging to size class 20-35cm in the shallow and eutrophic Tjeukemeer (The Netherlands) and compared it with food availability. Forsberg (1986) calculated food selection of elvers (±7cm) held in cages in a small acidified Swedish lake in relation to bottom fauna and zooplankton communities in the surroundings of the cages, while Henning and Zander (1981) studied the food and euryhyaline small-sized fish (including elvers) from a fresh water mud flat near Hamburg.

By analysing the stomach contents and food availability (benthos and plankton communities) in an experiment with two pond population of glass eels at different stocking rates it was possible to estimate the impact of food availability on feeding activity and growth of glass eel.

MATERIALS AND METHODS

Ponds

The two ponds stocked with glass eel are part of the fish culture centre "Volharding" at Rijkevorsel (Antwerp) and are the property of the Department of Nature Conservation and Development (Location on the NGI map 8/5-6: 224.8-175.0). The fish culture is in connection with the canal Dessel-Schoten. Both ponds are similar in shape (width 25m, length 50m, surface 0.125ha), depth (from 0.30m at the inlet side increasing with a gentle slope to 1.40m at the outlet), structure (the bottom consists of sand and mud) and water inflow

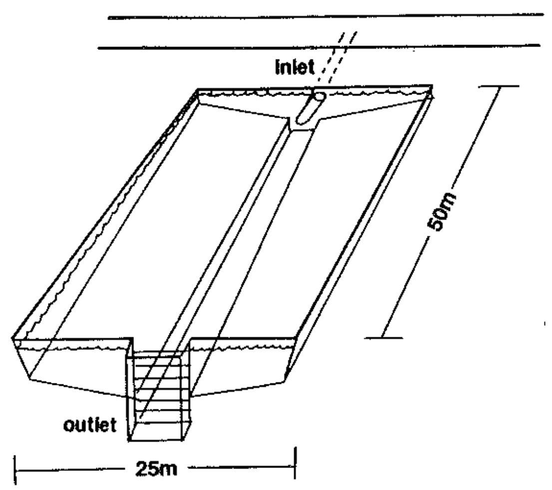

Figure 1: Schematic view of the ponds.

(Figure 1). Both ponds are temporary fish ponds which are kept dry during a part of the year (winter time). They are located in an area where the soil consists mainly of sand (lowland peat), consequently natural productivity of the ponds is rather low. The ponds were flooded with unfiltered water from the canal on 29 March, 1989.

Glass eel

The glass eel stocked in both ponds on 9 May originated from Scotland, and were transported by air to the Netherlands before continuing its route to Belgium by lorry. Before stocking a sample of glass eel was taken to analyse their weight and length. Stocking rates in both ponds were different: 877g glass eel (7.016kg/ha) in pond LD (Low Density) and 3304g glass eel (26.432kg/ha) in pond HD (High Density).

In order to study the feeding regime of the glass eel over the year, a sample of approximately 10 eels per pond was caught at regular time interval during the growing season (approximately every 3 weeks) by wading through the ponds with a dipnet. Both ponds were harvested on 25 October, the eels remained 169 days in the ponds. After weighing and measuring all sampled eels were immediately fixed and preserved in formaldehyde, in order to analyse the stomach content.

Pond HD was sampled intensively during 24 hours in September 5th and 6th to study diurnal feeding patterns. A sample of 10 eels was fished every three hours. By fishing subsequently in different parts of the pond disturbance of the feeding behaviour of the eels was avoided.

Stomach analysis

Preserved eels were dissected and stomach and gut were weighed. The fullness of the stomach was estimated as a percentage of its volume (on a 5% accuracy basis). This was also done for the intestine of the eels sampled during the 24h cycle. The intestine was divided in three parts. The different food items in the stomach were identified and their numbers were counted. For most of the food items dry weight was determined.

Benthos occurrence and water quality

The benthos population was studied by analysing bottom samples taken with a plexiglass benthos corer (diameter = 5.3cm). The core sample was restricted to an upper bottom layer of 5cm. In order to study benthic biomass and changes in species composition (succession) of the benthos population, 336 core samples (2 ponds, 12 samples per pond, 14 sampling dates) were taken over a period of 7 months over both ponds. The first samples were taken directly after flooding the ponds (thus before the stocking with eels). After sieving, bottom samples were stained with bengalic red, fixed by formalin and preserved in alcohol. All organisms were fixed, identified and counted. On each sampling date the water quality was analysed. Table 1 gives an overview of the extreme values measured in both ponds. All water parameters were normal with the exception of a high ammonium level (5.14 mg/l) recorded on 13 September, which was probably caused by intensive wading activity during the 24h sampling.

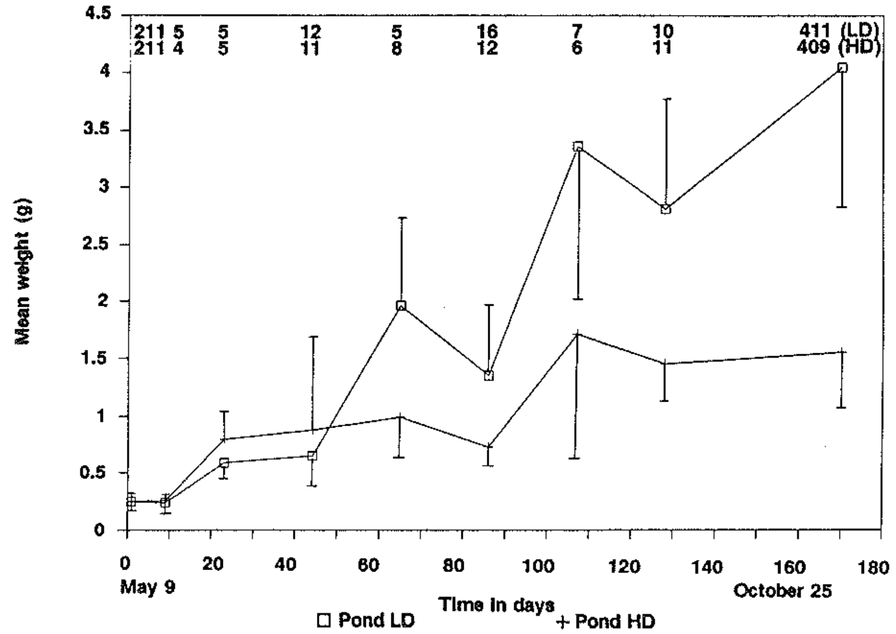

Figure 2: Growth curves of the LD (low density) and HD (high density) populations, vertical bars indicate s.d. On top: sample size.

RESULTS

EEL GROWTH

Although on most sampling dates sample size was limited (with the exception of samples taken at stocking and harvest time) some conclusions can be drawn concerning growth of elvers in fish ponds.

The growth curves of both eel populations are illustrated in Figure 2. The glass eel grew from 0.23 ± 0.04g (7.0cm) to 4.05 ± 1.20g (14.7cm) in pond LD and to 1.55 ± 0.45g (10.9cm) in pond HD during approximately $5\frac{1}{2}$ months. Taking into account the low productivity of the ponds and the mean length increments of the glass eel populations during this rather short period (7.7cm for pond LD and 3.9cm for pond HD) it is obvious that eel growth potential is considerable in such ponds. Once more it is evident that the stocking density has a clear and significant effect on eel growth. From day 65 on the mean weight of the sampled eels of pond LD was significantly higher than the mean weight of the eels in the HD pond. This density dependent growth is even more striking when comparing the length frequency distributions of both populations at harvest time (Figure 3). Length-weight relationships at harvest time for the two populations are represented in Figure 4. The corresponding parameters are given in Table 2. When comparing the length-weight relationships between eels of both ponds belonging to the same length class (9.4-14.2cm) b-value was significantly higher ($P < 0.001$) for the LD population (LD: $b = 3.475$, $N = 152$, $R^2 = 0.92$; HD: $b = 3.043$, $N = 390$, $R^2 = 0.88$).

BENTHOS COMMUNITY IN THE PONDS

Species diversity

The analysis of the 336 core samples resulted in the identification of a large variety of species. In total at least 43 different species could be recognised, belonging to 21 orders and 32 families. A list of species (groups) occurring in the ponds is presented in Table 3.

Abundance and succession of the benthos species in function of time

Organisms occurring in these temporary ponds must be able to survive in a dormant stage in the pond bottom during the dry period, or are colonising the pond with the inflowing channel water. Some are able to move in or out of the water (e.g. some adult aquatic insects).

By counting all the different organisms in the samples it is possible to analyse abundance and distribution in time of the species. By comparing the frequency distributions of the benthic species, it is quite clear that succession is the main characteristic of this benthos pond community. Data are shown in a kite diagram in

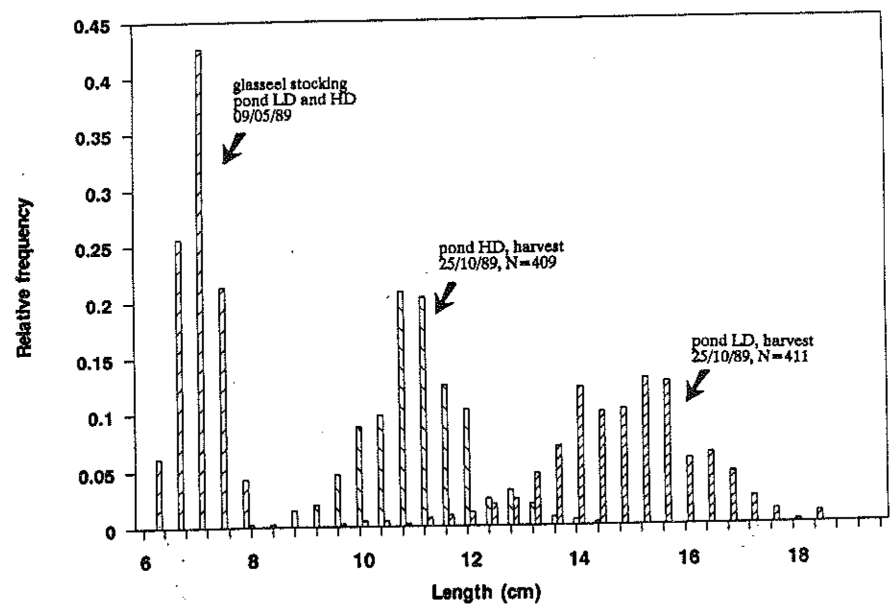

Figure 3: Length frequency of the glass eels at stocking time (9 May) and of the LD and HD population at harvest time (25 October).

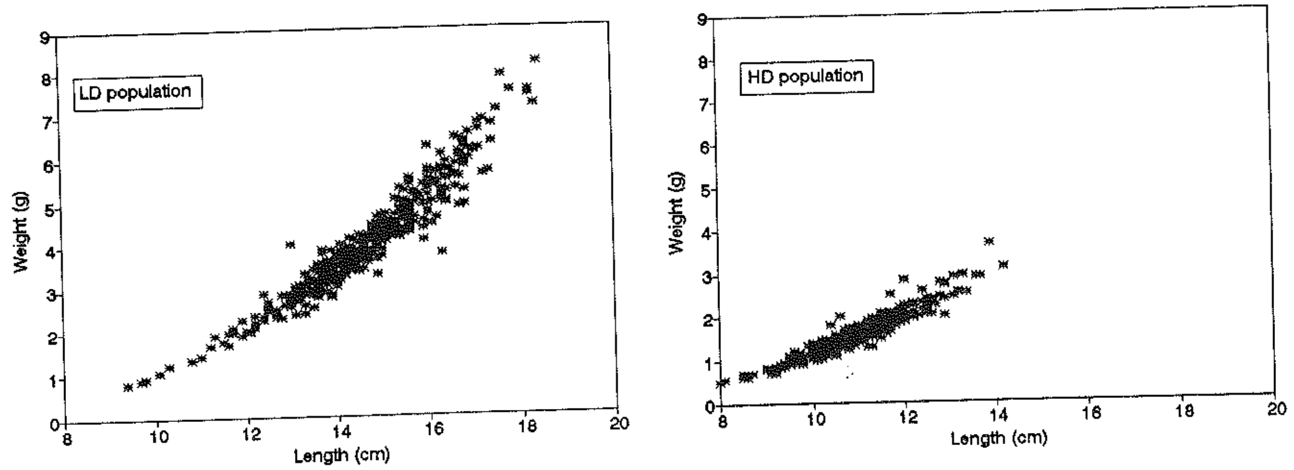

Figure 4: Length-weight relationship from a sample of eels of the LD and HD population at harvest time (25 October).

Figure 5. Worm-like species, Lumbriculidae/Dorydrilidae and nematodes were found in large numbers directly after filling the pond, followed up, later in the season, by Aelosomatidae and Tubificidae. Also among the chironomid species, succession is obvious. The Tanytarsini, which were the most abundant chironomids (reaching densities up to 20,000 individuals per square meter), colonise the ponds very rapidly and are followed up by a peak of Chironomini before going up again into another peak. After that, Tanypodinae increase and reach maximum numbers in mid summer. This is the time Ceratopogonidae increased to attain large densities in the late summer. Also zooplanktonic Crustacea, which also were represented in the benthos samples, showed succession patterns: copepods were frequent in the beginning of the season, while the daphnid species have their maximum in late summer and autumn. Nymphs of Ephemeroptera (*Centroptilum* and *Caenis*) were found especially in the late season. Although they didn't reach high numbers, their biomass was quite important, due to their larger size.

Effects of predation

As we were particularly interested to know if it was possible to observe the effects of eel predation on the benthos populations, a hypothesis test was carried out comparing the paired means of species density per sampling date. The results are represented in Table 4.

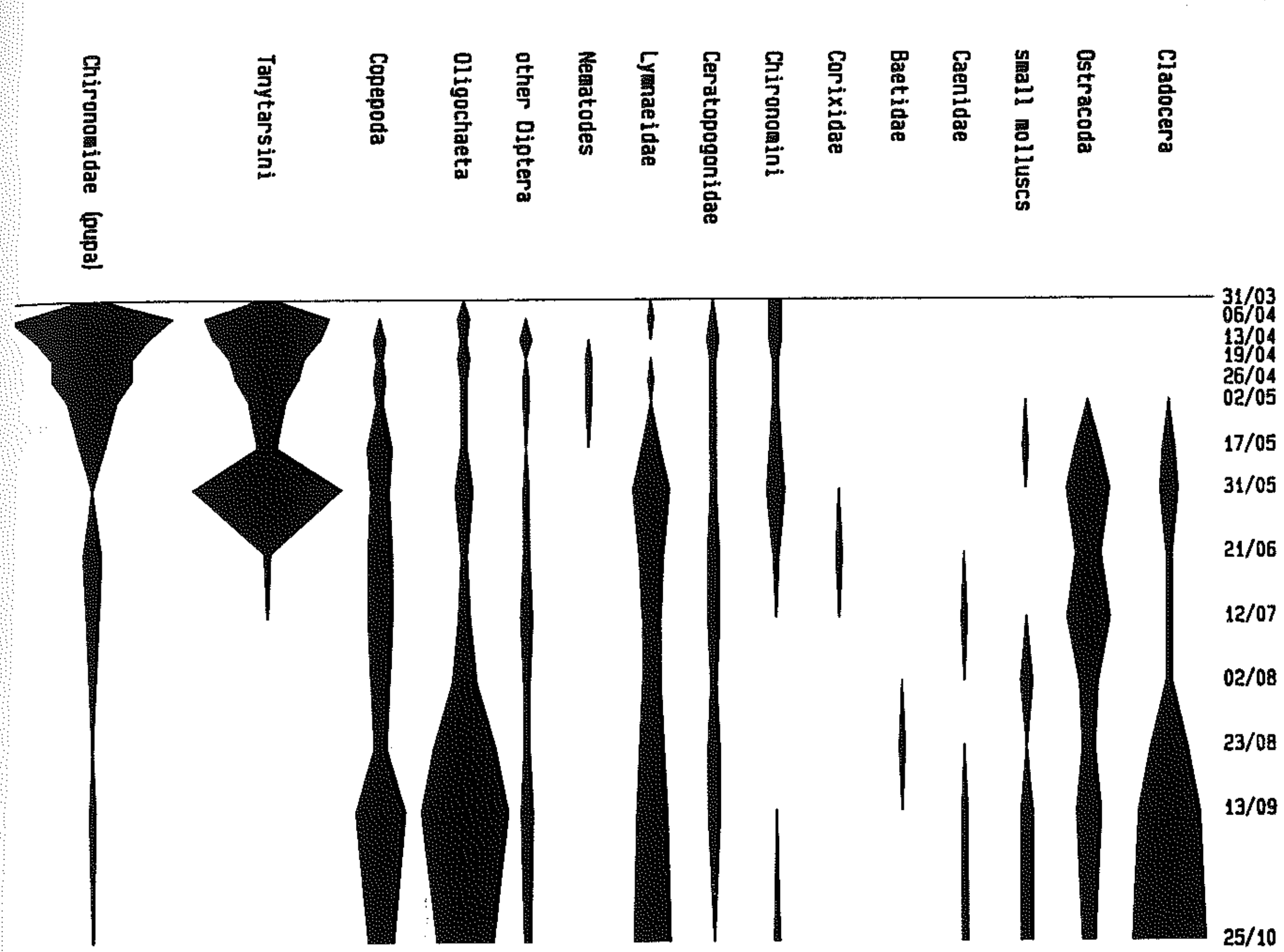

Figure 5: Kite diagram representing the densities of the most common benthic species over the year in pond LD.

Five species or species groups were found to be significantly different between the two ponds for the whole period after stocking. The densities of Cladocera, Ostracoda, Nematoda and two *Lymnaea* species were significantly higher in pond LD than in pond HD. Furthermore, during some periods of the year also other species groups such as Tanytarsini, Tanypodinae, Caenidae, Ceratopogonidae and most of the other molluscs were found to be more common in the LD pond.

FEEDING ACTIVITY OF THE ELVERS

Diversity of prey organisms

The stomach content of 155 eels sampled at regular time intervals between May and October 1989 (94 eels with non-empty stomachs) and during the 24h cycle on 5 and 6 September (61 eels with non-empty stomachs) was quite diverse: the identified benthic and zooplanktonic prey organisms in the stomachs are indicated underlined in Table 3. In addition, sometimes detritus which could not be identified, vegetable material and undetermined eggs were present.

Relative quantitative importance of the preys

A wide variety of organisms in the ponds is shown to be potential prey for the eels. However all species groups are not taken to the same extent and the relative quantitative importance (in dry weight) of the various prey organisms may differ considerably as shown in Figure 6, calculated on 61 stomachs collected on 5 and 6 September (length of these eels was 10.1 ± 0.8cm). During this period Cladocera and Ceratopogonidae were quantitatively the most important preys (together constituting in dry weight 68% of the food). Elvers in this length class (8.6-13.2cm) are shown thus not only to be benthivorous, but also planktivorous. Baetidae, Dytiscidae, Chironomidae, Caenidae, Oligochaetae, Trichoptera, Sphaeridae and Odonata are less common.

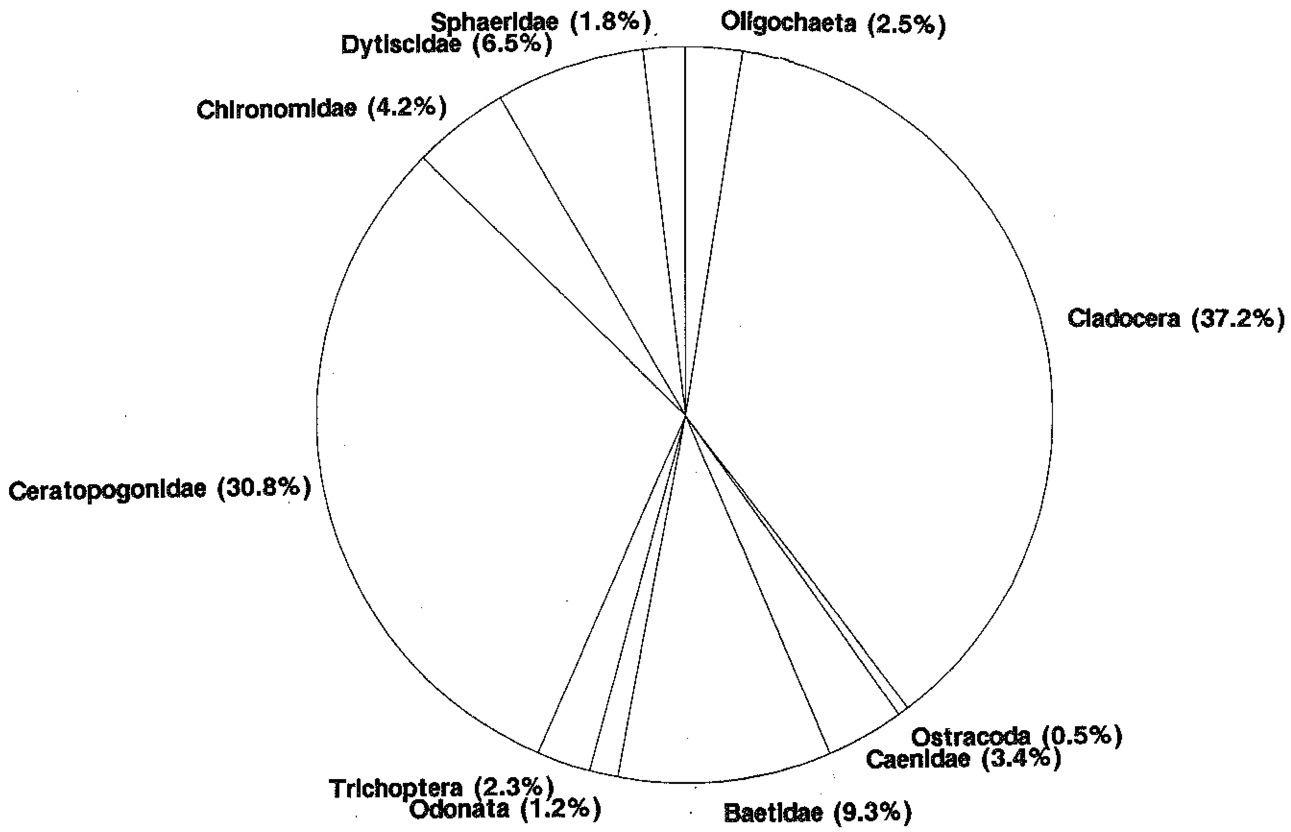

Figure 6: Relative quantitative importance (based on dry weights) of the various food items of eels sampled on 5 and 6 September in the HD pond.

Seasonal changes in feeding regime

Table 3 showed that the elvers predate on a wide variety of prey organisms. Obviously, the succession in the benthic community will influence thoroughly the feeding regime of the eels. By using the frequency of occurrence method (Hynes, 1950 and Windell, 1968) for the various organisms throughout the year it became evident that the food changed through the season. The results are represented in a kite diagram in Figure 7. In May, eels were mainly predating on Cladocera and Chironomids and to a lesser extent on Oligochaeta. The intake of Oligochaeta ceased during June but Ceratopogonidae became more important. Later, in July Caenidae (Ephemeroptera) appeared in the diet while Cladocera and Ceratopogonidae still had high occurrence frequencies. Chironomids became less important. From July on, Odonata were found in the stomachs and at the end of the season Sphaeridae were also present in the diet.

Food selection

The numbers of different food items in the stomachs which were at least 25% full (97 stomachs) were counted and their frequencies are presented in Figure 8. In 16% of these stomachs only one food item was present and in 54% of the cases 2 or 3 different food components were found. As the diversity of available food is quite important, and 70% of the fish had 3 or less different food items in their stomachs it may be concluded that even if the elvers may predate on a whole variety of prey organisms they usually predate in a more or less selective way.

It was obvious that some eels specialised in certain predation techniques. This was evident while analysing the stomachs sampled on 5 and 6 September. Figure 9 represents the frequencies of the proportion of the stomach content (expressed as weight percentages) filled with Cladocera. A proportion of eels (13%) fed mostly exclusively on Cladocera (90 to 100% of the dry weight of stomach contents). This illustrates the very selective feeding activity of these fishes, which requires an adapted predation strategy.

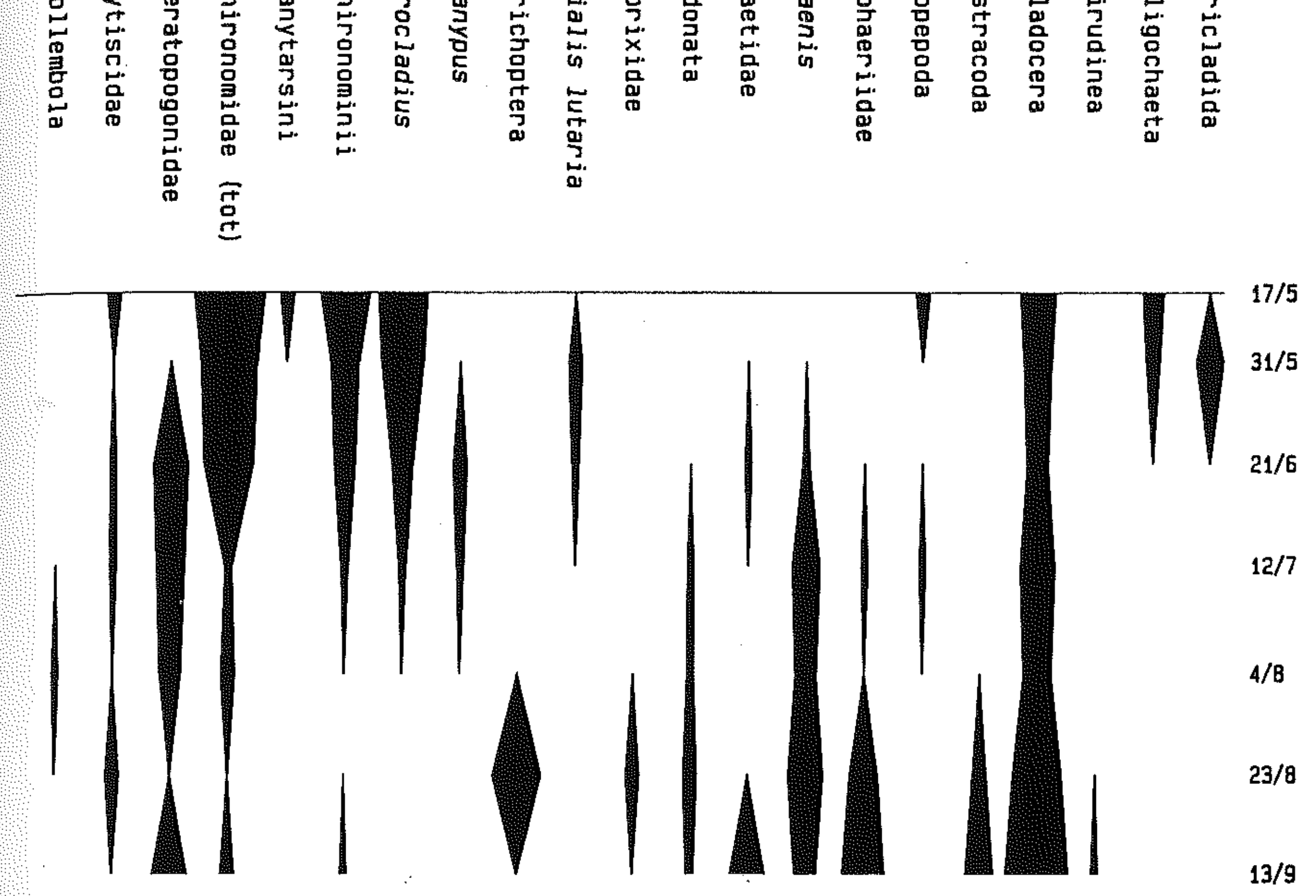

Figure 7: Changes in the frequency of occurrence (in % of food-containing stomachs) of the various food items throughout the year.

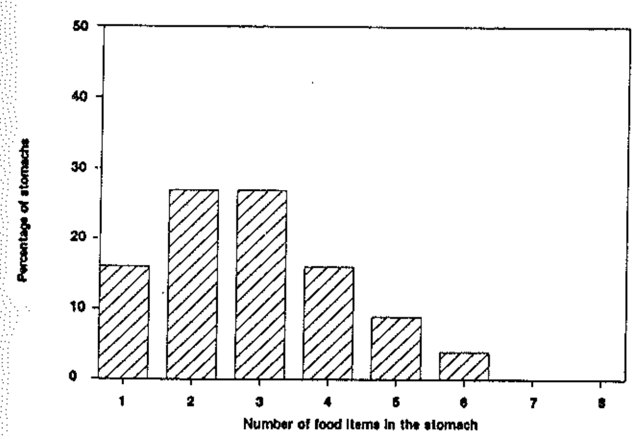

Figure 8: Frequency of occurence of the number of different food items in the stomach which were more than 25% filled.

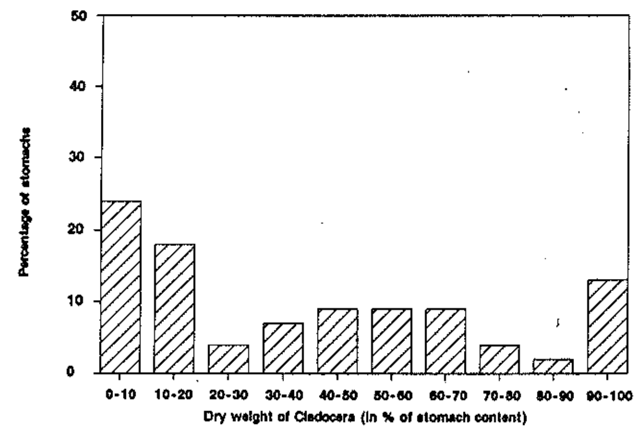

Figure 9: Feeding preference of some eels for Cladocera (stomach with degree of fullness >25%) on 5 and 6 September in the HD pond.

Daily feeding rhythmics

The daily feeding activity of the eels in the ponds was studied by analysing the stomachs of eels sampled on a 24h cycle in September. A total of 81 fish were sampled during 9 3h intervals. The mean relative wet weight of the stomach content (in percentage of the wet body weight of the fish) is expressed according to the time of the day in Figure 10. The stomach content (and consequently) the feeding activity was minimal in the afternoon and increased gradually at night. Eel feeding activity in the ponds was essentially nocturnal.

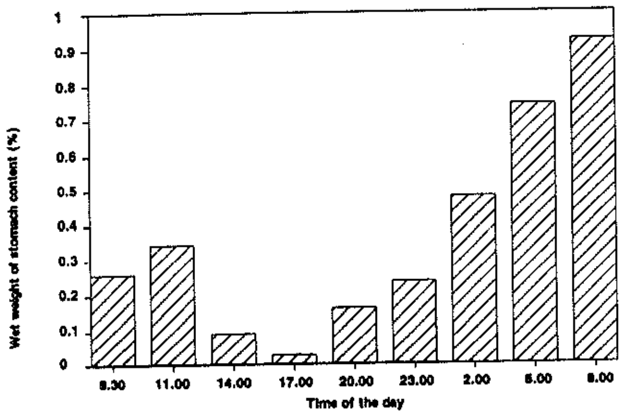

Figure 10: Wet weight of the stomach contents as percentage of the wet body weight of the fish according to time of day on 5 and 6 September in the HD pond.

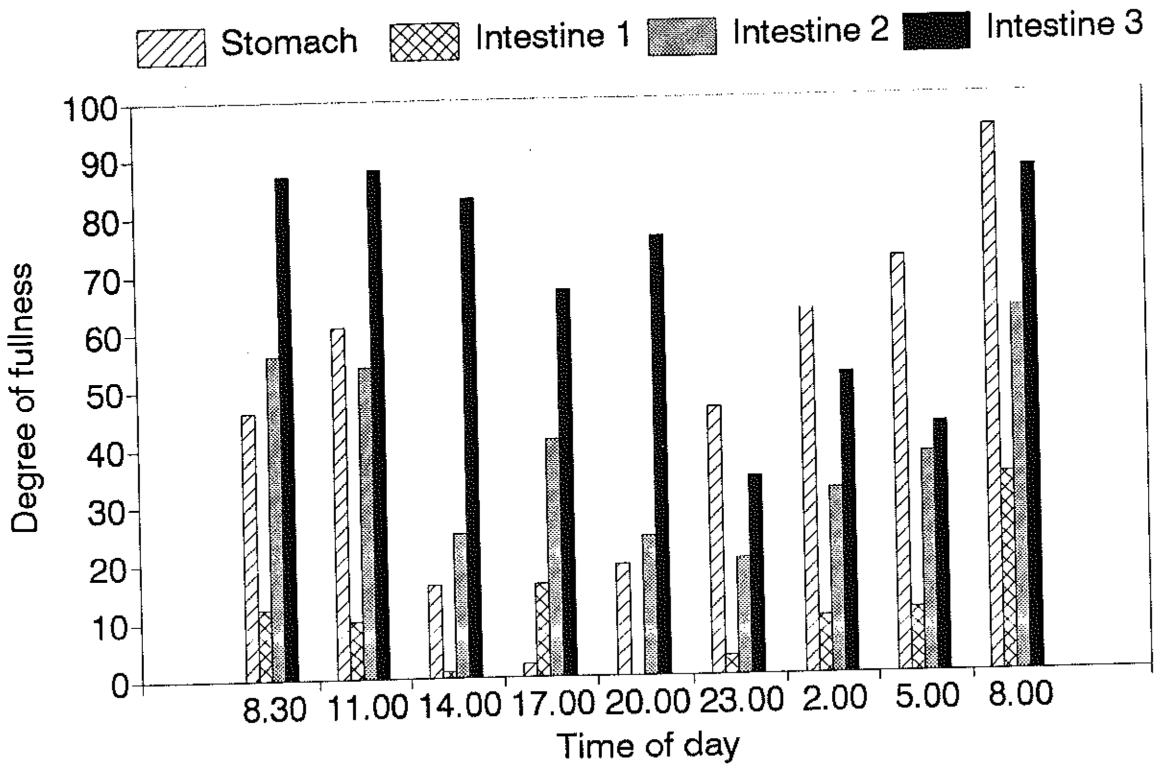

Figure 11: Mean degree of fullness of the stomach and the three parts of the intestine during the 24h cycle (pond HD, September 5 and 6).

Digestion

The intestine was divided into three equal parts of which the degree of fullness was estimated. Every 3 hours mean degree of fullness was calculated for the stomach and the different parts of the intestine. Results are shown in Figure 11.

In order to describe the course of the food within the digestive tract these data were subjected to an analysis of cosinor (Halberg et al., 1970). Table 5 gives the description of the function for the degree of fullness for the various parts of the digestive tract according to time of day.

As can be seen in Figure 12, the maximal degree of fullness of the various parts of the digestive tract shifts from 5-6 hours (stomach) to 8-9 hours (intestine part 1) to 9-10 hours (intestine part 2) and finally to 13-14 hours for the third part of the intestine. By comparing the time of maximal degree of fullness of stomach

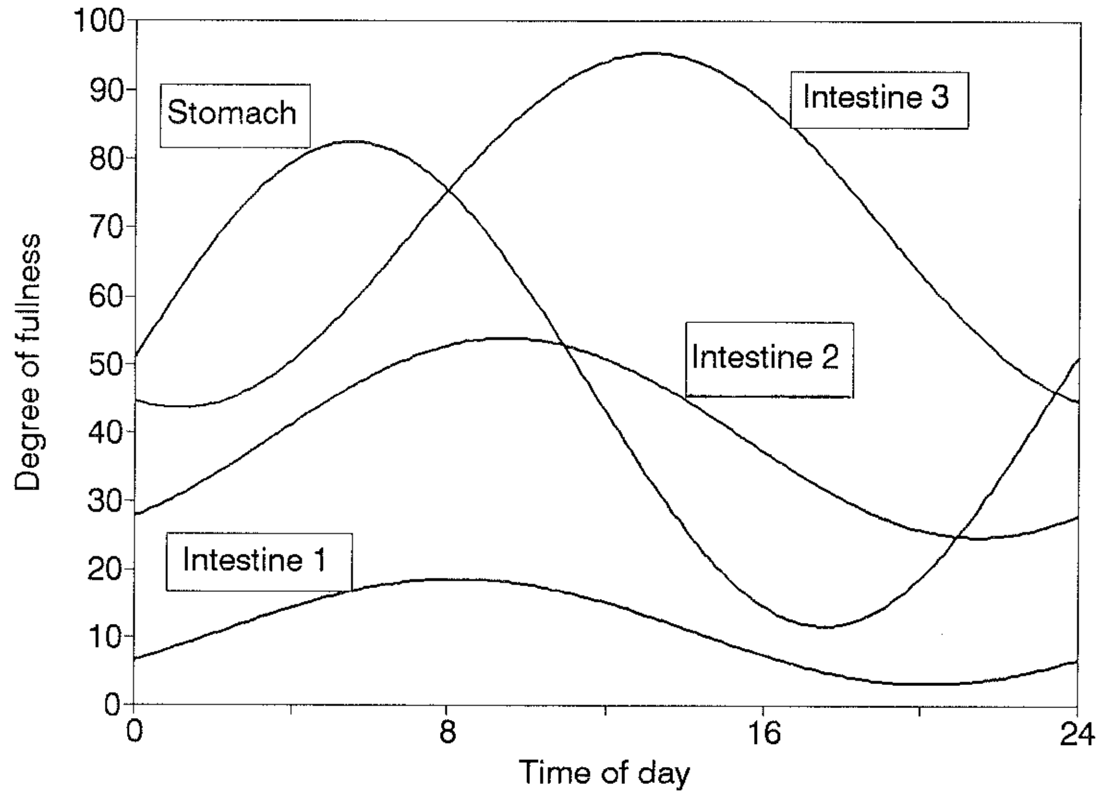

Figure 12: Most probably functions describing the fluctuations of the degree of fullness over a 24h period for the various parts of the digestive tract.

and the first part of the intestine an approximate digestion rate of 3-4 hours can be deduced (water temperature in this 24h cycle was fluctuating between 15.5°C at night and 19.5°C during the day).

The large amplitude (35.3%) of the stomach fullness function illustrates that the fullness of the stomach can vary considerably, part 1 and 2 of the digestive tract however, have only small amplitudes and small mean fullness degrees: the food is shifting gradually and in small quantities towards the end of the intestine, where it can accumulate (25.9% amplitude and 69.4% mean fullness degree for part 3 of the intestine).

Daily consumption rate

The daily consumption rate of the eels was estimated using the equation following Neveu, 1981

$$C = 24.S.R$$

S being the mean value of the stomach content over a day (in mg dry weight per g eel). R being the stomachal evacuation value

$$R = \frac{\log Y_2 - \log Y_1}{t_2 - t_1}$$

(Y_1 = dry weight at time t_1 and Y_2 = dry weight at time t_2)

For the 24h cycle of 5 and 6 September (pond HD) a daily consumption rate of 4.38mg dry weight per g eel was calculated (S = 1.69mg dry weight per g body weight).

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Table 1: Extreme values of water quality parameters in both ponds.

	Pond LD	Pond HD
T (°C)	5.1-26.4	5.8-25.7
pH	7.37-9.70	6.68-9.80
O_2 (mg/l)	8.5-16.9	4.1-19.0
Conductivity (µS/cm)	188-418	186-387
NH_4^+ (mg/l)	0.17-0.80	0.14-5.14
NO_2^- (mg/l)	0.08-0.27	0.08-0.21
NO_3^- (mg/l)	16.7-93.0	12.4-97.0
SO_4^{2-} (mg/l)	27.2-72.2	22.0-74.3
PO_4^{3-} (mg/l)	0.10-1.57	0.08-1.14

Table 2: Length-weight relationship (log W = log a + b log L) of the elver populations of the LD and HD pond at harvest time (25th October 1989).

Pond	Min Length (cm)	Max Length (cm)	N	Log a	b	R^2
LD	9.4	18.4	411	−3.066	3.138	0.95
HD	8.0	14.2	409	−3.116	3.174	0.91

Table 3: List of species or species groups recognised in the benthos samples. Species or species groups which are underlined were found to be present in eel stomachs.

PHYLUM	CLASS	ORDER	FAMILY	SPECIES
Arthropoda	Crustacea	Copepoda		
		Cladocera	Daphniidae	
		Ostracoda		
	Insecta	Diptera	Chironomidae	
			subfam. Chironominae	
			tribus Chironomini	*Chironomus*
				Polypedilum
			tribus Tanytarsini	
			subfam. Tanypodinae	*Procladius*
				Tanypus
			subfam. Podonominae	
			subfam. Orthocladiinae	
			Ceratopogonidae	
			Chironomidae (pupa)	
			Cecidomyiidae	
			Simuliidae	
			Culicidae	
			Chloropidae	
			Dixidae (pupa)	
		Ephemeroptera	Baetidae	*Centroptilum luteolum*
			Caenidae	*Caenis horaria*
				Caenis robusta
		Trichoptera	Philopotamidae	
			Sericotamidae	*Brachycentrus*
		Hemiptera	Corixidae	*Corixa punctata*
		Coleoptera	Dytiscidae	*Dytiscus*
				Bidessus
				Hyphydrus ovatus
		Homoptera	Aphididae	
		Odonata	Gomphidae	*Gomphus*
		Collembola	Poduridae	*Sminthurides*?
		Megaloptera	Sialidae	*Sialis lutaria*
		Hymenoptera	Cephidae	
	Arachnida	Acari	Hydrachnellae (Hydracarina)	*Piona*
		Araneae		
Mollusca	Gastropoda	Basommatophora	Lymnaeidae	*Lymnaea peregra*
				Lymnaea ovata
				Lymnaea auricularia
				Lymnaea catascopium
				Myxas glutinosa
			Physidae	*Physa fontinalis*
		Mesogastropoda	Valvatidae	*Valvata macrostoma*
				Valvata cristata
		Stylommatophora	Succineidae	*Succinea putris*
	Bivalvia		Sphaeriidae	
Annelida	Oligochaeta		Aeolosomatidae	
			Tubificidae	
			Lumbriculidae +Dorydrilidae	
Nematoda	Hirudinae	Rhynchobdellae	Glossiphonidae	*Glossiphonia*

Table 4: Probability values from hypothesis tests (SAS-statistics) comparing the means of the benthos densities (12 samples per pond) per sampling date between the benthos species densities of pond LD and HD. Probability values <0.05 (*) indicate a significant difference between the species densities of the two ponds over the whole period (May-October 1989).

Copepoda	0.1869	*Lymnaea peregra*	0.0013*
Cladocera	0.0183*	*Lymnaea ovata*	0.0077*
Ostracoda	0.0311*	Ceratopogonidae	0.1898
Tanytarsini	0.1780	Aeolosomatidae	0.1284
Chironomini	0.1339	Tubificidae	0.4367
Tanypodinae	0.2016	Lumbriculidae + Dorydrilidae	0.0725
Podonominae	0.2244	Nematodes	0.0325*
Orthocladiinae	0.1753		

Table 5: Mathematical description of the degree of fullness of the parts of the digestive tract according to time (in hour) of the day (DF = degree of fullness, ST = stomach, I1 = intestine part 1, etc. . .).

$$DF_{ST} = 47.029 + 35.349 \cos [0.262(t - 5,565)]$$
$$DF_{I1} = 10.870 + 7.712 \cos [0.262(t - 8.224)]$$
$$DF_{I2} = 39.275 + 14.563 \cos [0.262(t - 9.489)]$$
$$DF_{I3} = 69.420 + 25.887 \cos [0.262(t - 13.118)]$$

The effect of eel on fish stock composition in lakes — preliminary results

by

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ABSTRACT

The paper presents the results of studies on the effect of eel upon the stocks of bream and roach in lakes. It was found that high densities of eel decreased the densities of bream and roach in lakes as well as the proportion of small-sized specimens. In eutrophic waters, in which the two species overdevelop and their growth rate is inhibited, this effect of eel is regarded as beneficial for the lake ecosystem and the fish stock composition.

INTRODUCTION

The problem of the effect of eel on fish stock composition in lakes has been raised a long time ago, both by science as well as by fishermen (Rudnicki et al 1971, Leopold 1986). Attention was drawn most of all to the role of eel as a predatory fish, i.e. to its possible ameliorating effect, limiting the abundance of less valuable and weed fish species. The problem becomes of special importance in view of progressing lake eutrophication, which on the one hand enhances the development of weed fish and simultaneously inhibits their growth rate (overdevelopment of small-sized specimens), and on the other hand eliminates predators which otherwise might control these unwanted fish (Leopold et al 1986, Bnińska and Leopold 1990). In view of this, it is important to know whether the eel does really affect other fish species in lakes, and especially the fish stock composition.

This paper presents preliminary results of studies devoted to these problems.

In Poland over 90% of total lake area is managed by the state fish farms. All these lakes are commercially exploited. As a rule commercial exploitation is not selective, but the whole fish stock is exploited with a more or less constant effort. Moreover, the fishing effort has not changed much in the past 40 years (Bnińska and Leopold 1990). A variety of fishing gear is used in each lake; summer seines and various trap nets in summer, winter seines in winter. Each lake is usually exploited for about eight months a year. All commercial catches are recorded for each lake separately and embrace all species caught as well as their size-classes. At the end of each month these are summed up and recorded in the so-called Lake Books (kept for every lake), and the annual yields are also recorded at the end of each calendar year. In view of the above, commercial catch statistics reflect quite well fish stock composition and fish densities in lakes (Bnińska and Leopold 1990, Bnińska 1991), and these were used in the analyses.

MATERIAL AND METHODS

Analyses were based on commercial catch statistics for 166 lakes, covering periods from 25 to 40 years, average 34 years for each lake. Total area of the lakes amounted to 73,215 ha i.e. over one quarter of the total lake area in Poland. The lakes were randomly selected from among the records possessed by the Department of Fishery Bioeconomics. Individual lake area ranged from 50 to 9,880 ha.

Average annual catches were calculated for each lake for eel, three sizes of bream (Table 1) and two sizes of roach (over and under 0.2 kg).

The analyses were based on arithmetic as well as weighted arithmetic means. In the latter lake area was used as the weight and the means were calculated according to the formula (Spiegel 1972):

$$\frac{\sum wX}{\sum w}$$

where: w — lake in ha
X — catch in kg/ha/year

Percentage of eel in the fish catch was related to both percentage share of bream and roach catches as well as their absolute levels (in kg/ha), the latter reflecting densities of these species in the lake ecosystems.

Percentage of eel in total fish catches from the lakes under study ranged from 0% 28.7%.
In the first step the lakes were divided into two groups, with eel catch below and above 5% of total fish catch and the two groups were compared. In the second step it was decided to make a sharper distinction and to perform more detailed analyses. Thus, lakes with less than 1% and more than 10% of eel were selected and the two groups were compared.
Significance of the differences between the groups was established with Student's t test.

RESULTS AND DISCUSSION

This paper presents preliminary results of a research project aimed at determining the effect of eel on fish stock composition in lakes. Bream and roach were chosen in the first stage because the two species predominate in Polish lakes and tend to overdevelop in the course of lake eutrophication (Bnińska and Leopold 1990). Moreover, share of small-sized roach and small-sized bream increases with increasing lake trophy (Leopold, Bnińska, Nowak 1986, Bnińska and Leopold 1990, Bnińska 1991). In addition to this, roach and bream (and especially small roach and small bream) are of very little if any economic value, and are generally regarded as weed fish.
The lakes were divided according to the percentage of eel in total fish catches, and not to the absolute levels of eel catch. This approach was adopted because obviously, for instance, 3 kg per ha of eel in case of total fish catch of 20 kg/ha would affect the fish stock more than 4 kg/ha in case of total fish catch of 40 kg/ha. In the first case eel represents 15% of the first, stock, in the second only 10%.
The analyses were based on both arithmetic and weighted means. As stated by Freund (1967) it is an error to use the arithmetic means to describe a general picture from a set of data in which the relative importance of particular data points is not the same. In these cases weighted arithmetic means should be used (Freund 1967, Loftus 1988). In our study the weighted means, with lake area as the weight, were certainly more appropriate. However, when weighted means are used, it is not possible to estimate the significance of the difference, because no valid standard deviation can be calculated (Spiegel 1972). In view of this, arithmetic means were calculated first, and these were used to determine the significance of the differences between the lake groups. It is accepted (Spiegel 1972, Loftus and Loftus 1988) that if the differences between the arithmetic means are significant, and the weighted means accentuate these differences, then the latter are equally significant.
This was exactly the case in our study. All differences between the lake groups were statistically significant when arithmetic means were used (at the level of significance at least 0.05), and weighted means made these differences even more pronounced, as illustrated in Table 1. Thus, we may conclude that the results are statistically significant.
Eel catches below 5% occurred in 60 lakes, above 5% in 106 lakes. In the first group eel catches averaged 0.76 kg/ha, in the latter 2.66 kg/ha.
The composition of bream and roach stocks in the two groups differed considerably (Fig. 1). The differences were more pronounced in the case of bream. In lakes with low proportion of eel, the percentage of small bream was much higher than in lakes with a high proportion. A similar trend, although less pronounced, was noted for roach (Fig. 1).

More detailed analyses were performed on lakes with extremely low (below 1%) and extremely high (over 10%) proportion of eel. The first group comprised 13 lakes with total area of 1,380 ha, the second 35 lakes, total 10,280 ha. Eel catch in the first group amounted on the average to 0.21 kg/ha when no attention was paid to lake area, and to 0.43 kg/ha when means weighted by the area were used. The respective values for the other group were 3.65 and 3.54 kg/ha.
The results point to a beneficial effect of eel on the composition of the stocks of small value cyprinids. Composition of bream stocks in lakes with more than 10% of eel was much more satisfactory than in lakes with less than 1% (Fig. 2). The proportion of large bream was almost twice as high and that of small bream almost three times lower.

Eel had a beneficial effect also on roach stocks, decreasing the proportion of small-sized roach (Fig. 2).
The same pattern is noticeable also when absolute values are taken into consideration. The catch of small roach amounted to 8.69 kg/ha in lakes with less than 1% of eel and to 5.16 kg/ha in lakes with more than 10% of eel when arithmetic means were calculated, and to 10.24 kg/ha and 5.57 kg/ha respectively when weighted means were used. The respective values for bream are presented in Table 1.
A question may be asked whether these differences in the composition of bream and roach stocks are really caused by eel, or whether they result from different trophic status of lakes in the two groups.
Increasing lake eutrophication induces definite changes in the fish stock composition. Its most common symptom consists of the fact that the proportion of less valuable cyprinids (bream, roach and white bream) in the stock increases while that of the more valuable littoral cyprinids (tench, crucian carp) decreases (Leopold, Bnińska. Nowak 1986, Bnińska and Leopold 1990, Bnińska 1991). In order to check whether there were some differences as to the trophic status between the two lake groups, the composition of their natural

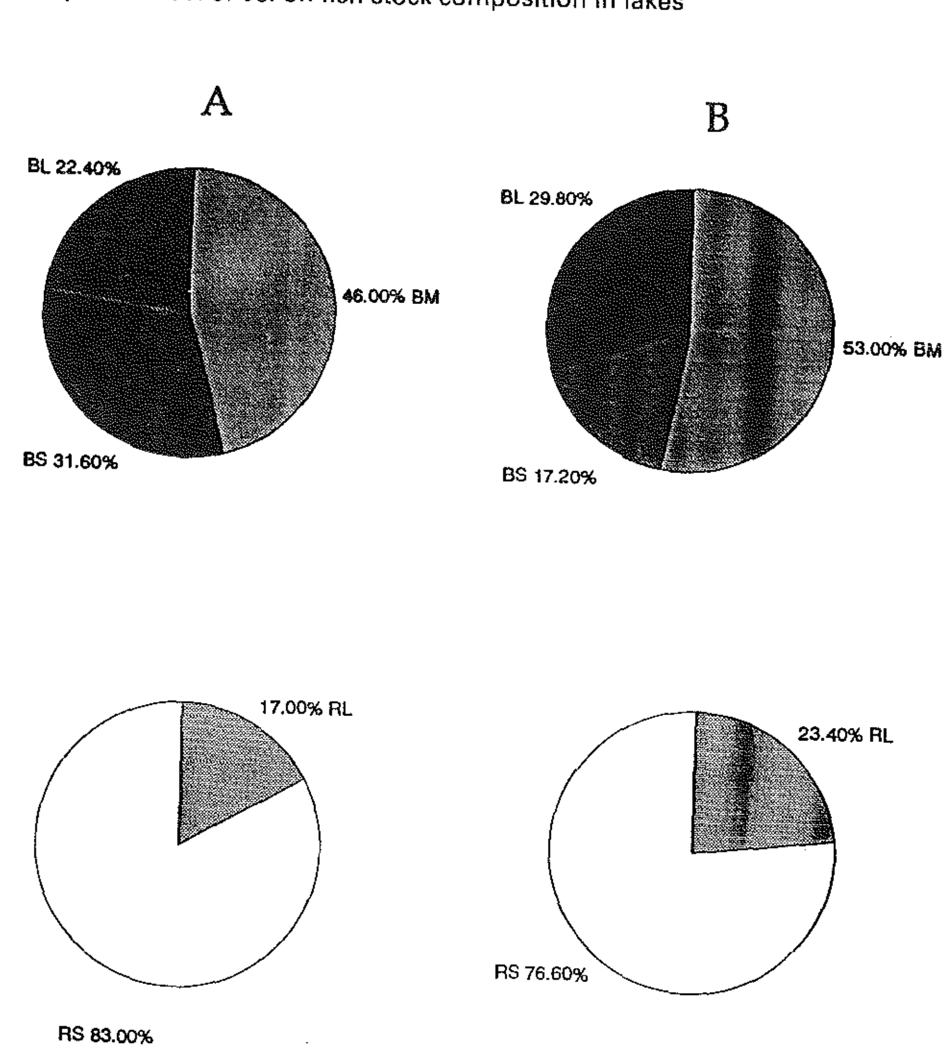

Figure 1: Size composition of bream and roach catches in lakes with less than 5% of eel (A), and more than 5% of eel (B). BL — large bream, BM — medium bream, BS — small bream, RL — large roach, RS — small roach.

fish stocks has been determined. Since the eel in Polish lakes originates totally from artificial stocking (Moriarty, Bnińska, Leopold 1990) it has been excluded from this analysis.
The proportion of the valuable littoral cyprinids tench and crucian carp may be taken as an indicator of trophic status (Leopold, Bnińska, Nowak 1986, Bnińska and Leopold 1990). The lakes with less than 1% of eel contained 15.3% valuable cyprinids and those with over 10% eel only 3.9%. It is clear that the large densities of eel were found in the more eutrophic waters.
As it is known (Leopold, Bnińska, Nowak 1986, Bnińska and Leopold 1990, Bnińska 1991) the proportion of small bream and small roach should be higher in more eutrophic lakes. In the lakes under study the situation was quite the opposite (Tab. 1). Hence, we can assume that we deal here with the effect of the eel on the stock of less valuable cyprinids.
Beneficial effect of eel on lake ecosystems has been already suggested by some authors. Rudnicki, Waluga and Waluś (1971) stated that ". . eel is an omnivorous fish. It feeds also on weed fish . . . thereby having a beneficial effect on the fishery management as it controls the stocks of undesirable species". Musatov (1969) stated that eel could act as an ameliorator of fish stocks in lakes, mostly by being a competitor for food with weed fish, and by feeding on their eggs and fry.
The results presented here are of a preliminary character and should be confirmed by more thorough studies which should include also studies on the feeding behaviour of eel in eutrophic lakes.

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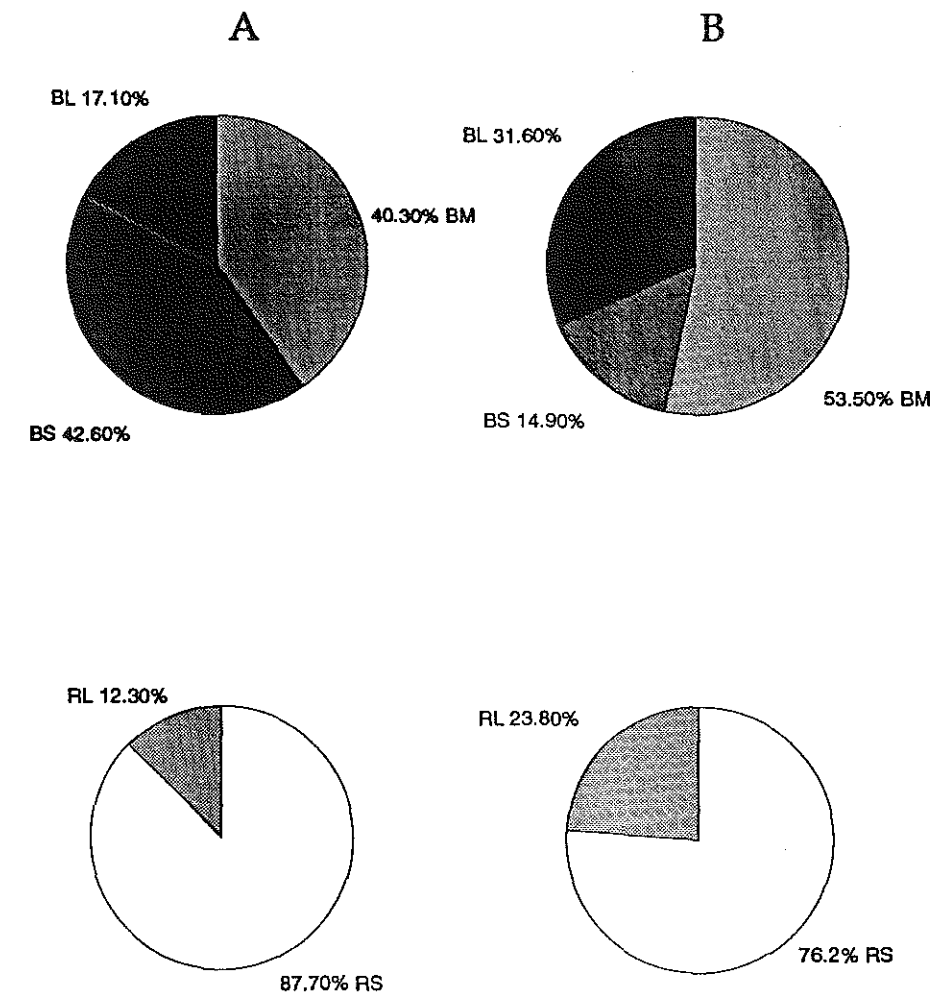

Figure 2: Size composition of bream and roach catches in lakes with less than 1% of eel (A), and more than 10% of eel (B). BL — large bream, BM — medium bream, BS — small bream, RL — large roach, RS — small roach.

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Table 1. Size composition of bream catches in lakes with low and high percentage of eel.

	Eel catch below 1%		Eel catch above 10%	
	means (kg/ha)			
	arithmetic	weighted	arithmetic	weighted
Large > 1 kg	0.92	1.50	1.82	1.81
Medium < > 0.5 kg	2.03	3.53	3.18	3.06
Small < 0.5 kg	2.23	3.74	1.29	0.85

Variations in population structure and growth rate of eels in the Dunkellin river system, western Ireland

by

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ABSTRACT

An electrofishing survey of small lowlying alkaline streams in western Ireland revealed that yellow eels comprised 20% by number and 52% by weight of the total fish catch. Eels were widespread in the system, occurring at fourteen of the nineteen sites electrofished. A total of 1,235 eels were sampled, a large proportion of which were in the 10-25 cm size range. Estimated eel densities and biomasses at 14 sites varied from 0.03-1.34/m^2 and 0.27-37.2/m^2 respectively. The average annual growth for undifferentiated and male eels up to age 10 was estimated to be about 2.5 cm per year.

INTRODUCTION

The freshwater fish fauna of Ireland is considered to be a depauperate one, whose composition reflects the incomplete post-glacial recolonization of the island. Eels, along with nine other migratory or euryhaline species, are thought to be native, whereas a further fourteen species are regarded as introductions (Wilson, 1986). Because of their special biogeographic status, and because they are widely distributed among Ireland's inland and estuarine habitats, ecological studies of Irish eels are of interest. The only reliable data available on eel population densities in Irish river systems is that provided by Moriarty (1989), who obtained samples of eels from sections of the River Nore catchment, where fish were being eliminated by means of the chemical piscicide rotenone, following a pollution incident. Electrofishing surveys have proved to be a valuable method of investigating eel populations in several countries (Larsen, 1972; Hussein, 1981; Aprahamian 1986 and Legault, 1987) although, reservations have been expressed as to its efficiency by some authors (Naismith and Knights, 1990).

The present study describes population structure, growth and biomass of eel populations sampled by electrofishing in the Dunkellin catchment. The relationships between the eel stocks and the physical parameters were examined in an effort to determine the important factors that may influence the population biology of eels in the river system. This catchment was chosen for special study because of its relatively small size, productive lowland basin, and because high natural recruitment of eels appears to take place. The river and associated wetlands have been the subjects of a variety of ecological investigations in recent years because of a proposal to alter the hydrology of this river system by channelization.

Study area

The Dunkellin river system (Figure 1) drains an area of approximately 400 sq. km in the west of Ireland (Lat. 53°N Long. 9°W). The catchment is relatively low lying, its highest points being drained by the head-waters of the Rafford stream in the northeastern section of the catchment (90-120 m above sea level). There is relatively little standing water with the exception of Lough Rea and Rahasane Turlough. The karst limestone nature of the bedrock in the area means that many stretches of the Dunkellin River itself and tributaries in the southern and eastern parts of the catchment can suffer from effects of drought. The annual mean rainfall is 1,170 mm. Mean daily air temperatures vary from 5.0°C to 15°C (Rohan, 1975). Stream temperatures generally approximate to mean daily air temperatures. The catchment can be divided into three main subsections: (A) the Rafford river (B) the Dunkellin river and (C) the Aggard stream, (Figure 1). Some of the physical and chemical characteristics of the river are presented in Table 1.

MATERIAL AND METHODS

Fish populations were investigated by means of electrofishing surveys at nineteen locations in the catchment area during the autumn of 1986 and 1987 (Fig. 1). Stream sections were fished using pulsed DC, 500 and 100 cycles per second, with a Honda 2.5 Kw, 220 volt generator positioned on the steam bank. Sections were fished upstream by two operators, using dip nets which acted as anodes, towards a weighted stop net (1 cm mesh). All eels sampled were retained. Other fish were sorted according to species, counted, and weighed in batches using Pesola spring balances, to the nearest 0.1 g in the case of small samples. Fish

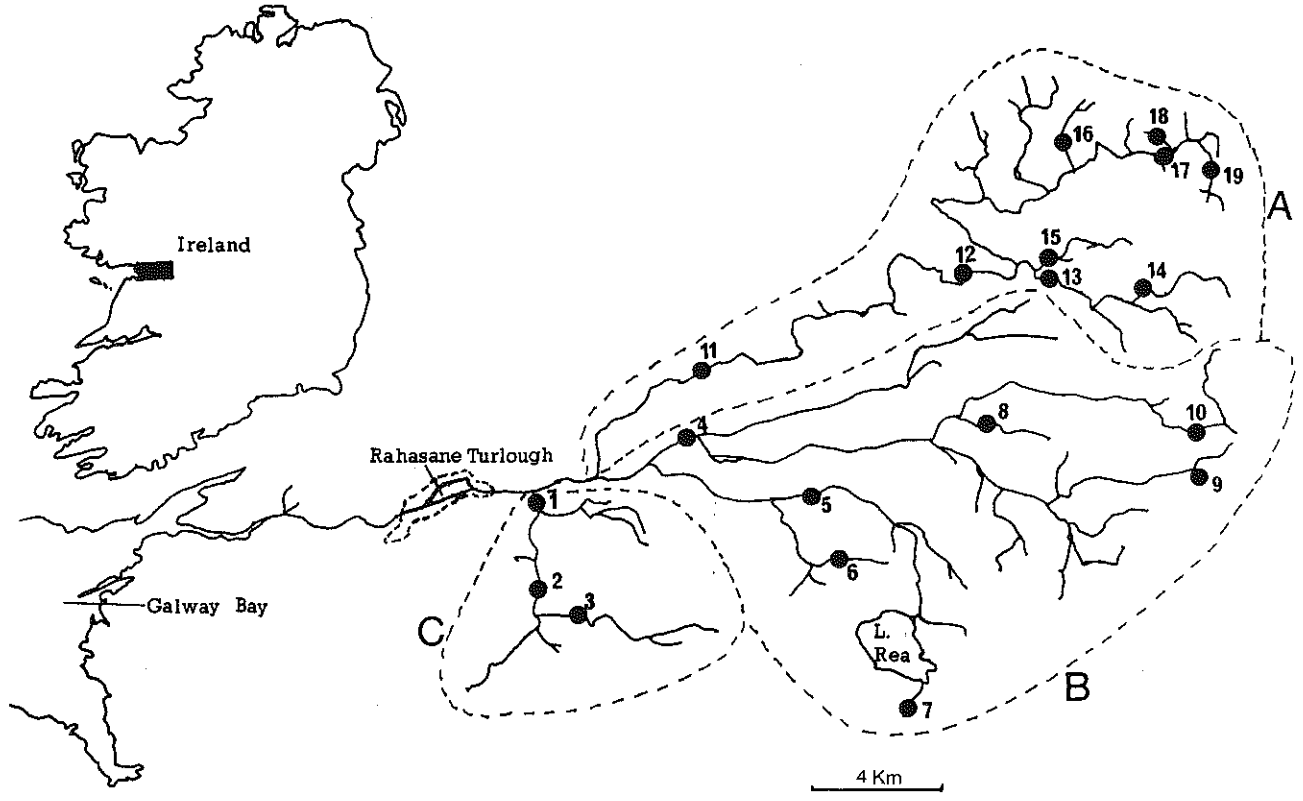

Figure 1. The Dunkellin Catchment showing the river subsections: (A) the Rafford River, (B) the Dunkellin River and (C) the Aggard Stream.

other than eels were returned alive to the steams after completion of full electrofishing procedures. Each section was fished three times, at approximately one hour intervals. Densities were estimated using the method described by Leslie and Davis (1939).

The water velocity was determined by means of triple measurements of the rate of flow of a largely submerged float. Depth measurements were made at approximately 0.5 m intervals across stream sections at a number of points 10 m apart, where the width was also recorded. Samples of water were anlaysed on sampling dates and conductivity, pH and water colour (Hazen units) were noted (Table 1).

Age determination using otoliths was carried out by the burning and cracking methods as described by Christensen (1964) and modified by Moriarty (1973) and Hu and Todd (1981). Interpretation of ring structure followed that of Moriarty (1973, 1983) and Penaz and Tesch (1970). All otoliths were examined twice and if these readings differed, a third reading was taken. Eels were sexed by a morphological examination of the gonads. The von Bertalanffy equation was fitted to length at age data using the Fortran BCG 2 programme (Abramson, 1971). Computer analyses were undertaken using programmes available in the Clustan (Wishart, 1987) and SPSS (Anon., 1986) packages.

RESULTS

Fish belonging to ten species were found. The species recorded were: Brook lamprey, *Lampetra planeri,* (Bloch), trout, *Salmo trutta* L., Salmon parr, *Salmo salar* L., pike, *Esox lucius* L., gudgeon, *Gobio gobio* (L.), stoneloach, *Noemacheilus barbatulus* L., eel, *Anguilla anguilla* (L.), three-spined stickleback *Gasterosteus aculeatus* L., nine-spined stickleback, *Pungitius pungitius* L. and perch, *Perca fluviatilis* L. The overall composition of the species assemblages is summarised in Figure 2.

Distribution and abundance

Eels were widely distributed within the river system and were found at 14 of the 19 sites electrofished. They accounted for 20% of the total number of fish recorded, being surpassed only by the stickleback *Gasterosteus*

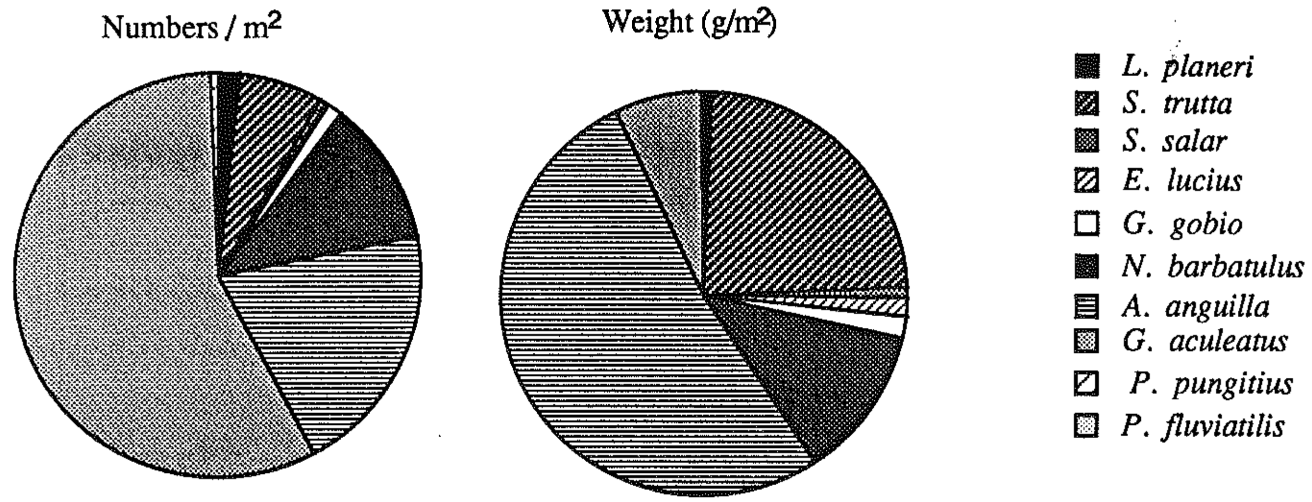

Figure 2. Species composition by weight and numbers per unit area of all fish sampled in the Dunkellin River.

aculeatus (Figure 2). Eels were the most important species by weight, making up 52% of the total fish biomass. There was considerable variation in density and biomass between sites (Table 2). Densities ranged from $0.03/m^2$ to $1.34/m^2$ (mean = $0.57/m^2$) and eels represented between 3% and 88% of total fish numbers. Eel biomass varied from $0.27g/m^2$ to $37.2g/m^2$ (mean = $12.45g/m^2$) and they accounted for 14% to 86% of the total fish weight. Eel biomass variation between the sites was strongly correlated with variation in eel densities (r_s 0.898, $p \leq .001$).

Analysis of the relationships between the primary eel population parameters, such as density and biomass, and the environmental data available for the sites (Table 1) was complicated by the high degree of statistical association (Spearman Rank Correlation Coefficients) between the environmental variables themselves. Eel density was significantly ($p < .05$) correlated to all of the environmental variables except temperature, conductivity and vegetation cover, while eel biomass was significantly related to all but two of the variables: conductivity and vegetation cover. However, the strongest correlations with eel density ($p \leq .001$) were with stream volume and the proximity of the site to the sea and altitude. In the case of biomass the strongest correlations ($p \leq .001$) were with stream order, width, depth, volume and proximity to the sea.

A cluster analysis (Lance-Williams flexible sorting method) of sites based on the environmental data (Figure 3) produced two principal clusters. Group 1 which was composed of nine sites could be further divided into two subgroups; subgroup 1a: the Aggard Stream sub-section and subgroup 1b: the mid reaches of the catchment. The second principal cluster, Group 2, was composed of the small shallow low order streams from the head-waters of the catchment (10 sites) and could be further subdivided into two subgroups; subgroup 2a: was made up of the head-water sites of the Dunkellin sub-section and subgroup 2b was mainly composed of the head-water sites of the Rafford sub-section. These two clusters of sites were highly significantly different (Mann-Whitney U test, $p \leq .005$) from each other in respect of six variables, volume, area, width, stream order, depth, length and altitude. Highest eel densities and biomasses were associated with sites from the group 1 cluster with a mean density and standing crop of 0.77 eels/m^2 and $18.19g/m^2$ compared with $0.1/m^2$ and $2.18g/m^2$ for the sites in group 2.

Eel Size

The length of eels within the catchment ranged from 8.6 to 59.4 cm (Table 3), however, 67% of the eels samples were between 10 and 25cm. The larger eels tended to occur in the 3rd and 4th order lowland sections of the catchment (sites 4, 5 and 11) (cluster subgroup 1b). The smallest eels occurred at site 3 (cluster subgroup 1a) (mean length = 13.31 ± 0.5). Eel weight ranged from 0.56g to 408.22g. The smaller eels were found at sites 3, 13 and 14. Mean weight at these sites was less than 10g (Table 3).

Length-weight relationships, overall, (for all eels sampled, n=1,235) and for each of 12 sites, (where n>10) were analysed using the equation $W=aL^b$ (where W=weight, L=length and a and b represent the intercept and the slope, respectively, of the linear transformed version of the equation). In all cases the values for b were greater than 3. Values for b at individual sites ranged from 3.1 to 3.3. Overall, (n=1,235) the value for b was 3.232 ± 0.013 indicating that the eels were in good condition and had increased weight for length above isometric growth.

Sex Ratio

Over 63% of the eels were sexually undifferentiated. Sexually differentiated males comprised 29.2% of the sampled population while females accounted for only 7.4%. The largest proportions of sexually differentiated

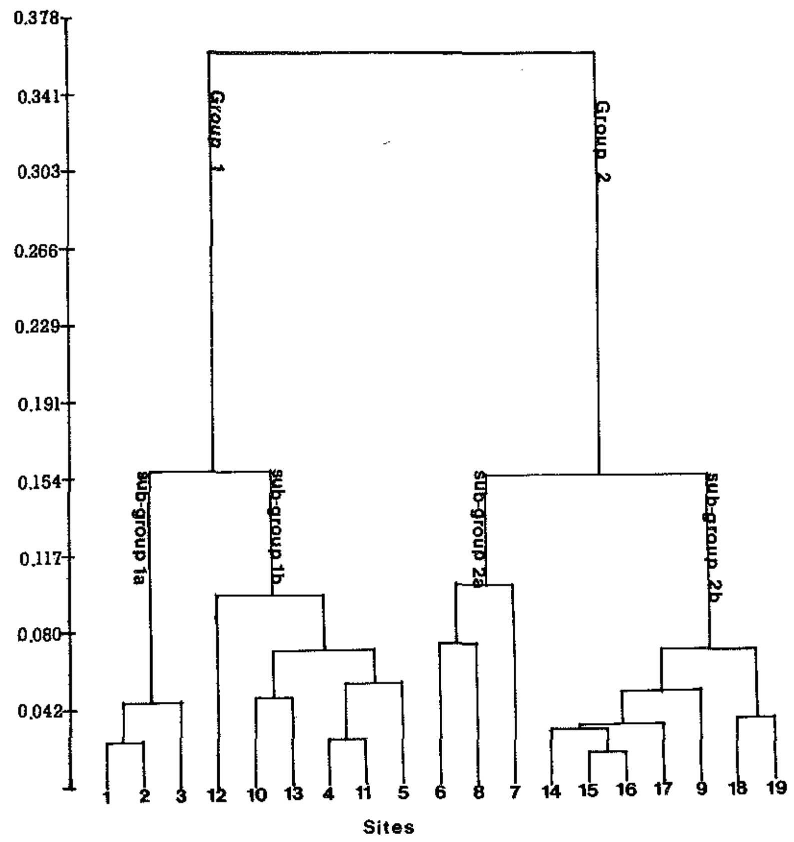

Figure 3. Dendrogram of the cluster analysis using the site characteristics (Table 1) (Lance-Williams flexible sorting method).

eels were found in the mid reaches of the Dunkellin sub-section of the catchment (Sites 4, 5 (cluster subgroup 1b) and 6 (cluster subgroup 2a)), close to Lough Rea (Table 2).

Age and Growth

Fish from 11 sites were aged (n=628). Age frequency distributions generally paralleled the pattern exhibited by the length/weight data for the sites (Table 4). The ages ranged from 1 to 21 years. The greater proportion of older fish were caught in the lower to middle reaches (cluster subgroup 1b) of the Dunkellin and Rafford subsections of the river system. Some of these were silver eels. The eels at site 13 (cluster subgroup 1b) were markedly younger (mean age=4.0 years.) than those at other sites. Mean ages at sites varied from 4.0 to 8.8. There was considerable overlap in sizes of eels of different age classes (Table 5). Female eels were generally larger than males/undifferentiated eels of the same age. Annual mean length increments were calculated for each age class of male/undifferentiated eels and separately, for female Dunkellin eels. The results indicated that for male/undifferentiated eels there was a linear increase in growth from ages 1 to 10 years (Table 5). Growth ranged from 1.1-3.9 cm per year and averaged 2.5 cm per year. After age 10 the growth appeared to slow down. However the sample sizes for these latter age categories of male/undifferentiated eels, and for female eels were small (Table 5) and no clear growth pattern was evident.

Von Bertalanffy growth curves were fitted to the length at age data (Figure 4). A separate growth curve was drawn for the males and undifferentiated eels (n=565), as well as the growth curve for the total population for which age data was available (n=628). The predicted maximum length L_∞ was over 18cm higher when female eels were included.

Undifferentiated and male eels	*All eels including females*
$L_\infty = 48.99 \pm 4.79$	$L_\infty = 67.29 \pm 9.34$
$K = 0.096 \pm 0.0779$	$K = 0.059 \pm 0.0145$
$t_0 = -0.6720 \pm 0.3933$	$t_0 = -0.9125 \pm 0.5006$

DISCUSSION

The Dunkellin river system contains ten species of freshwater fishes and is in this respect more diverse than many other small western Irish river systems. The overall results of the electrofishing survey (Fig. 2,

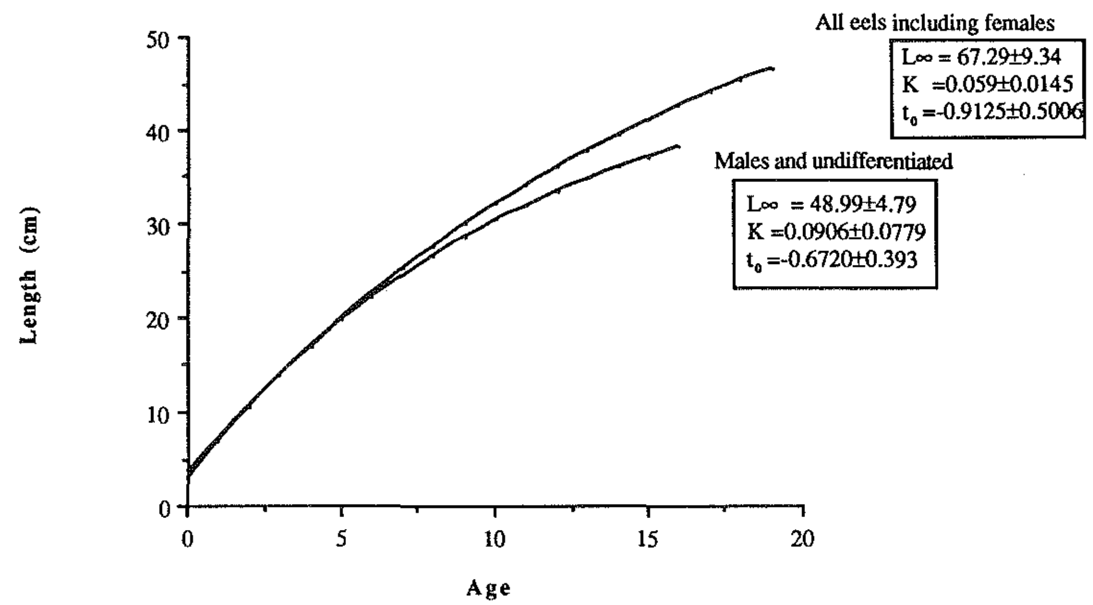

Figure 4. Von Bertalanffy growth curves for the Dunkellin River eels.

Table 2) illustrate the importance of eels in this river. Assessment of eel densities and biomass at individual sites showed clearly that eels were abundant throughout much of the river network. They were numerically the second most abundant species and were exceeded only by three-spined sticklebacks which were extremely numerous at a small number of sites. In terms of biomass the eel was the most important species in the catchment (Fig. 2, Table 2). With the exception of data provided by Moriarty (1989), who recorded somewhat lower eel densities and biomass in the River Nore, quantitative data are generally lacking in respect of Irish riverine eel populations. For this reason, it is not clear if this dominance of the River Dunkellin fish assemblages by eels is unusual in Ireland. Electrofishing surveys of some British and French river systems have found comparable variations in eel populations e.g. the River Tweed 0.13-0.93/m^2 and 3.6-32.8g/m^2 (Hussein, 1981); the River Severn, 0.006-1.139m/^{2} and 0.06-25.24g/m^2 (Aprahamian, 1986), and the Sevre Niortaise, 0.06-1.12/m^2 and 2.4-31.0g/m^2, (Legault, 1987). However not all British rivers harbour such high eel densities. Naismith and Knights (1991) in a recent survey in the River Thames reported values of 0-0.006m^2 and 0-7.0g/m^2.

It is widely accepted that electrofishing, like many other fish sampling methods can be size selective and that larger fish are more easily captured. However, in the case of eels perhaps due to their unusual body shape and benthic habits, observations on size selectivity of electrofishing gear have produced somewhat contradictory results (Chmielewski *et. al.* 1973; Naismith and Knights, 1990 and Zalewski and Cowx, 1990). In the present study most (81.3%) of the eels captured were less than 30 cm in length. Significant differences (Kruskall-Wallis, $p \leq .05$) were found between the size of eels captured in successive electrofishings at five sites (sites 1, 2, 3, 11 and 13) with progressively smaller fish being captured in each electrofishing. However, the proportion of eels captured in the first fishing (C_1) ranged from 44% to 80% (mean =58%) of the total catch (C_T), compared with pond experiments carried out by Naismith and Knights (1990) who found that the number of eels caught in the second electrofishing exceeded the number caught in the first fishing.

Eels are widespread within the catchment having been found at 14 of the 19 sites sampled. The five sites from which eels were absent were small, first and second order streams in the head-waters (cluster group 2). The highest densities and standing crops were found in the lower and mid reaches of the river (cluster group 1). Larger and older eels (as well as the highest proportion of sexually differentiated eels) were also found in the mid sections of the river. Larsen (1972) found a gradual disappearance of eels from shallow regions of a river in autumn and considered that this migration was temperature related. In the River Nivelle, Neveu (1981) found a relationship between eel densities and the water velocity and depth. Factors which appear to affect the distribution of eel within the Dunkellin system are the interrelated factors of proximity to the sea, altitude, stream order, the dimensions of stream sections. Distance from the sea has long been recognised as a major factor in the distribution of eels within a river system, greatest densities and biomasses being found in the mid and lower reaches of rivers (Larsen, 1972; Hussein, 1981; Aprahamian, 1986; Legault, 1987). The lack of young eels upstream in some larger rivers probably reflects the period of time necessary to migrate to these regions (Aprahamian, 1988). In the Dunkellin younger eels were also found in upsteam sites. This probably reflects the small size of the catchment area, with no site being more than 46km from the sea. The high density and standing crop of eels in the River Dunkellin suggests a high natural recruitment of eels. Although the catchment is small there are no major impediments to the upstream migration of eels and recruitment to the river system is probably favoured by its geographical location, situated as it is on the western edge of the European continent and flowing into the Atlantic Ocean.

The eels sampled in the Dunkellin were generally in good condition as indicated by the length/weight relationships. However this is to be expected since sample took place in the autumn following the favourable growth conditions of summer. Growth curves based on the von Bertalanffy model indicate that L_∞ is similar to that found for another Irish river system by Poole (1991) but are lower than L_∞ values obtained by Moriarty (1983) for the Irish River Barrow. Both of these authors based their von Bertalanffy models on back-calculations whereas in the present study they are based on length at age. Many of the published values of L_∞ are based on back-calculations and are for fast growing southern European eel stocks (Nagiec and Bahnsawy, 1990). Exceptions are a small Danish stream (Rasmussen and Therkildsen 1979) and Puck Bay (Baltic sea), (Filuk and Wiktor, 1988) where growth was estimated on length at age.

Variation in growth rate between individuals is particularly wide in the eel. However growth rates at each age in a particular habitat tend to be confined within reasonable limits (Pitcher and Hart, 1982). The average annual growth in different regions of Europe in different types of water and stocking densities is approximately 3 to 6 cm (Berg, 1989). The growth of eels in the Dunkellin system appears to be rather slow when compared with many other European habitats. However, other Irish studies for both lakes and large rivers have found growth rates of between 1.8 to 4.1 cm. per year (Moriarty, 1988), which is similar to that found in the present study. Slower growth rates (1.25 cm and 1.3 cm per year) have been found in two small oligotrophic streams in western Ireland (Poole, 1991). Population density, temperature and the quality of food available have been considered to be the main factors influencing individual growth (Tesch, 1977). In the case of the Dunkellin River eels, no evidence was obtained to suggest that growth rates varied in relation to density. Likewise food availability appeared to be consistently high throughout most of the river network. Berg (1989) suggested that temperature was the most important factor influencing eel growth. Most of the high growth populations are located at lower latitudes and most of the low growth populations are located at the higher latitudes (Fernandez-Delgado, *et al.*, 1989). It would appear that the Irish climate although mild, may restrict the potential growth of eels due to the generally low summer water temperatures.

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Table 1. Characteristics of the sampling sites.

Site number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Distance from Sea (km)	10	13	14	14	18	20	27	24	31	32	16	29	32	36	33	41	43	45	46
Altitude (m)	30	61	61	61	61	91	91	91	91	122	61	91	91	122	91	122	122	122	122
Stream order	3	3	2	3	3	1	1	1	1	2	4	4	2	1	2	2	2	1	2
Length of section (m)	40	50	55	45	55	30	35	31	28	30	39	45	50	33	40	30	33	27	30
Width (m)	5.24	4.08	3.97	4.60	3.40	1.50	1.00	0.93	2.40	3.09	5.64	6.80	3.90	1.95	1.92	2.50	3.48	0.60	1.33
Depth (m)	0.26	0.16	0.37	0.44	0.38	0.15	0.15	0.27	0.06	0.44	0.29	0.35	0.16	0.21	0.14	0.10	0.16	0.16	0.12
Area (m^2)	209.6	204.0	218.4	207.0	187.0	45.0	35.0	28.8	67.2	92.7	220.0	306.0	195.0	64.3	76.8	75.0	114.8	16.2	39.9
Volume (m^3)	54.5	32.6	80.8	91.1	71.1	6.7	5.2	7.8	4.0	40.8	63.8	107.1	31.2	13.5	10.8	7.5	18.4	2.6	4.8
Velocity (m/s)	0.40	0.38	0.19	1.00	0.29	0.30	0.40	0.42	0.25	0.14	1.00	0.30	0.20	0.59	0.12	0.01	0.32	0.30	0.12
Conductivity (μm/s)	660	680	620	560	560	650	680	630	400	600	430	450	480	480	450	460	440	410	410
pH	7.5	7.2	7.2	7.2	7.2	7.1	7.4	7.5	7.0	7.3	7.3	7.2	7.2	7.2	7.1	6.8	7.2	6.8	6.9
Temperature °C	13.2	13.0	14.0	12.0	8.5	12.5	13.5	8.0	14.5	12.5	11.0	14.0	15.0	8.5	14.5	12.5	13.5	13.0	12.0
% Instream vegetation	70	70	50	0	0	30	0	0	1	0	0	10	0	0	0	0	0	0	0
Water colour (Hazen units)	25	25	55	95	30	70	5	120	165	85	175	140	160	170	200	200	225	225	225

Table 2. Results of the electrofishing survey. #Biomass calculated using mean weight. *C_1 = no of eels captured in first fishing; C_T = no of eels captured in all three fishings.

Site	No/m^2	% of total fish population	g/m^2	% of total fish weight	*$C_1/C_{T\%}$	% Female	% Male	% Undifferentiated
1	1.13	60	18.13	45	52	02.6	33.3	64.0
2	1.34	67	23.16	68	55	02.6	34.3	63.0
3	0.35	13	1.28	38	44	0	02.1	97.9
4	0.85	40	37.20	70	61	17.4	40.6	41.0
5	0.48	50	24.30	50	54	31.1	47.3	21.6
6	0.27	9	6.82	47	67	08.3	50.0	41.7
7	0.00	0	0.00	0	—	—	—	—
8	0.52	28	9.63	80	80	0	33.3	66.7
9	0.00	0	0.00	0	—	—	—	—
10	0.46	88	6.87	86	47	10.0	20.0	70.0
11	1.03	56	25.67	68	60	07.8	31.7	60.5
12	0.25	27	8.13	66	48	13.1	26.2	60.7
13	1.02	28	6.76	21	64	0	06.5	93.5
14	0.03	3	0.27#	14	50	0	0	100
15	0.17	35	5.46	78	67	16.7	50.0	33.3
16	0.00	0	0.00	0	—	—	—	—
17	0.03	6	0.58#	16	67	0	0	100
18	0.00	0	0.00	0	0	—	—	—
19	0.00	0	0.00	0	0	—	—	—

Table 3. The size of eels at each site.

Site no	n	Mean weight (g)	SE	Range	Mean length (cm)	SE	Range
1	189	18.64	1.35	0.97-90.97	21.2	0.5	9.6-47.4
2	230	19.31	1.33	0.56-98.03	20.6	0.4	8.6-37.2
3	48	4.29	0.68	1.03-29.81	13.3	0.5	9.4-26.7
4	162	42.22	4.16	0.96-301.47	27.2	0.8	10.3-59.4
5	74	55.13	5.90	0.75-294.56	30.0	1.1	9.3-52.7
6	12	25.05	7.42	4.66-98.71	23.6	1.9	14.3-38.1
7	0	—	—	—	—	—	—
8	15	16.37	4.21	2.05-52.23	20.6	1.8	11.2-33.1
9	0	—	—	—	—	—	—
10	30	19.75	4.00	2.30-99.10	22.3	1.2	13.7-40.2
11	208	27.54	2.66	0.88-310.10	22.9	0.6	9.5-56.9
12	61	33.24	8.74	0.97-408.22	22.0	1.2	9.7-55.9
13	189	7.02	0.70	0.71-64.71	15.8	0.4	8.9-31.8
14	2	4.02	0.41	3.61-4.42	18.2	3.2	15.0-21.5
15	12	34.31	9.50	5.60-96.76	27.1	2.3	16.7-41.4
16	0	—	—	—	—	—	—
17	3	19.27	7.07	7.66-32.05	24.0	3.0	18.7-29
18	0	—	—	—	—	—	—
19	0	—	—	—	—	—	—

Table 4. The percentage frequency of eels in each age group at each site.

Site no	1	4	5	6	8	10	11	13	14	15	17
No of fish aged	99	85	70	12	15	30	146	154	2	12	3
Age											
1	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.3	0.0	0.0	0.0
2	3.0	0.0	4.3	0.0	0.0	0.0	1.4	12.3	0.0	0.0	0.0
3	3.0	1.2	1.4	0.0	0.0	3.3	11.6	22.1	0.0	0.0	0.0
4	16.2	5.9	5.7	8.3	6.7	13.3	4.1	33.1	50.0	16.7	0.0
5	19.2	11.8	1.0	25.0	26.7	20.0	11.6	14.3	0.0	16.7	0.0
6	27.3	10.6	8.6	8.3	26.7	0.0	19.2	8.4	50.0	8.3	33.3
7	14.1	11.8	20.0	25.0	13.3	10.0	8.9	8.4	0.0	8.3	33.3
8	8.1	12.9	15.7	16.7	0.0	3.3	5.5	0.0	0.0	16.7	0.0
9	3.0	15.3	12.9	0.0	13.3	6.7	3.4	0.0	0.0	8.3	0.0
10	2.0	8.2	10.0	8.3	0.0	0.0	1.4	0.0	0.0	8.3	33.3
11	1.0	3.5	2.9	0.0	13.3	0.0	4.8	0.0	0.0	8.3	0.0
12	0.0	2.4	1.4	0.0	0.0	6.7	9.6	0.0	0.0	0.0	0.0
13	2.0	3.5	2.9	0.0	0.0	3.3	3.4	0.0	0.0	8.3	0.0
14	0.0	4.7	1.4	0.0	0.0	0.0	4.1	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0
16	0.0	3.5	1.4	0.0	8.3	0.0	3.4	0.0	0.0	0.0	0.0
17	0.0	3.5	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0
21	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean age	6.1	8.8	8.7	5.8	7.3	6.4	8.1	4.0	8.0	7.5	5.0
SE	0.23	0.39	0.35	0.57	0.92	0.44	0.35	0.12	—	0.83	—

Table 5. Mean length and range in lengths of male and female eels at each age group.

	Males and undifferentiated eels				Females			
		Length (cm)				Length (cm)		
Age	n	Mean	SE	Range	n	Mean	SE	Range
1	4	9.8	0.1	09.7-10.1	0	—	—	—
2	24	10.9	0.2	08.9-13.3	0	—	—	—
3	61	13.1	0.3	09.3-18.9	0	—	—	—
4	91	15.9	0.3	10.6-23.5	0	—	—	—
5	86	18.3	0.3	11.2-27.8	1	39.7	—	—
6	97	21.2	0.4	14.9-31.4	1	36.1	—	—
7	61	24.1	0.5	16.5-31.9	2	33.8	6.4	27.4-40.2
8	44	28.0	0.5	21.5-34.9	5	30.8	1.9	24.7-34.9
9	29	29.7	0.8	21.0-38.0	6	36.6	2.9	28.7-45.7
10	20	32.3	0.8	25.4-40.3	6	33.4	1.8	29.5-41.4
11	13	33.0	0.8	28.6-37.5	6	37.7	2.2	29.6-45.6
12	15	32.1	0.6	28.0-36.0	5	34.1	1.3	29.6-36.7
13	6	37.2	0.9	34.2-40.2	7	41.2	1.9	33.4-47.4
14	4	32.4	0.6	30.7-33.4	8	44.3	2.3	34.2-54.0
15	3	35.7	1.2	33.4-36.9	3	39.1	0.6	38.2-40.3
16	3	32.7	2.3	28.2-35.0	6	48.1	3.0	38.1-56.9
17	1	33.8	—	—	3	51.6	4.6	43.6-59.4
18	2	33.3	2.6	30.7-35.8	1	52.7	—	—
19	1	35.7	—	—	1	52.3	—	—
20	0	—	—	—	1	43.6	—	—
21	0	—	—	—	1	50.0	—	—

A study of methods of estimating the size of eel populations in small streams

by

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A study was conducted to compare mark-recapture (weighted means method) (Begon, 1979), catch-depletion (Leslie & Davies and Carle & Strub methods) (Cowx, 1983) and mixed methods for estimating the size of a natural eel population in a tributary of the River Tagus (Portugal) below the Belver dam, 200km from the sea. Six electrofishing runs were conducted over two days on stop-netted stretches 100m long × 2m wide × 0.5m deep. Body lengths and weights were recorded and fish Floy-tagged at the beginning of the dorsal fin and released after each run.

A mixed method of analysis, combining mark-recapture and catch-depletion techniques, was applied. This involved the following data manipulations, where:—

f_i = proportion of first captures — ratio between first captures (untagged eels) and total catches (untagged and tagged eels) — in the ith sample.

m_i = number of tagged eels till the ith sample.

d_i = number of deaths during tagging operations till the ith sample.

am_i = number of active tagged eels till the ith sample (m_i-d_i).

am_f = theoretical number of active tagged eels when all the individuals of the population are caught.

d_f = total of deaths occurred during all tagging operations.

N_o = original population size.

The proportion of eels captured for the first time in the ith sample (f_i) was plotted against the number of active tagged eels (am_i) at that moment. From the resulting straight line (fitted using the least squares regression analysis), the final number of active tagged eels (am_f — X intercept) was estimated. The initial population size (N_o) was obtained by the addition of those eels which had died during tagging operations to the final number of active tagged eels ($N_o = am_f + d_f$). Confidence limits (95%) were estimated using the methodology applied on the computation of the regression analysis confidence limits.

If the probability of capture is the same for tagged and untagged individuals, the proportion of first captures will be lower in successive samples, even when total catches do not decrease. This reduces the error induced by differential daily activity.

As the number of eels caught did not decrease in successive samples, the assumption of catch-depletion methods (Cowx, 1983) that catchability must remain constant throughout the sampling period was violated. Statistical analysis showed that catches were not biased towards larger individuals and catches per minute did not decrease with time, therefore catch variations were not due to size selectivity or sampling duration.

Naismith & Knights (1990) stated that the tendency for catches not to decrease with successive sweeps, is very common when electrofishing for eels. According to these authors this feature can be explained by the body form and burrowing habits of such fish. Some individuals leave their burrows only after the first or second sweep. However, this behaviour can hardly explain the results obtained in this study since a quite variable capture pattern was observed during the survey.

Once the less effective catches were done in the afternoon, when eels are usually more inactive (Tesch, 1977), such variation seems to be connected with eel activity. Indicative of this feature is the fact that on the second day the untagged eel catches at noon were one half of the dusk catches.

Catchability was similar for tagged and untagged eels, showing that tagging operations had no significant effect on the activity of tagged individuals. Therefore, the basic assumptions of mark-recapture methods (Begon, 1979) were reasonably met in this experiment.

A considerable variation in the estimates was found, pointing out a great deal of variation related to the number of catches and different methods. However, all the methods applied to data from six catches gave results varying from 171 to 187 individuals (corresponding to a density of 0.9 individuals/m^2 and a biomass of 22.7 g/m^2). So, electrofishing in small streams proved to be efficient in estimating the size of eel populations.

No method had provided accurate estimates until the fourth sample had been performed, because several fishing operations had to be executed to ensure that a reasonable proportion of the population had been collected.

Both catch-depletion techniques failed to produce accurate estimates before the sixth sample. From these two methods the Carle & Strub model was considered more convenient and satisfactory producing approximate results with only 4 or 5 samples, and providing shorter confidence limits.

Because there was a considerable variability in the proportion of the population taken in each catch, due to eel differential daily activity, an appropriate strategy for improving the accuracy of catch-depletion estimates is to conduct the survey in successive days at the same hour. If this is not acceptable because of the large amount of time and effort required, another effective strategy would be to increase the number of fishing operations, since results showed an increasing accuracy when more samples were performed.

Both the weighted mean capture/recapture and the mixed methods gave relatively accurate and similar results for more than 3 samples. However the mixed method produced shorter confidence limits, for all but one case, and enabled testing of whether tagging operations affected tagged eel activity.

The application of such methods involves more means than catch-depletion techniques but produced accurate results with less fishing effort, providing time economy and reducing stream disturbance.

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Management of the Corrib eel fishery, Ireland

by

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The potential value of the eel fishery of the River Corrib and associated lakes was calculated at £5 million per annum. The current reported yearly catch of eels was 50 tonnes, value £150,000. Clearly there is scope for major development.

The lake fishery used traditional long-line techniques until 1971 when this was replaced by fyke netting. Development of the full potential would require the operation of a management plan to include stock enhancement, control of all commercial operations and, ultimately, the establishment of a processing industry to produce top quality smoked eel for the European market.

The paper gives an account of the fishery since 1961 together with the results of the latest research work on the eel stocks. This showed that serious reduction of stocks had taken place in the south basin of Lough Corrib but that elsewhere in the system conditions were similar to those which obtained in the 1960's. Development of the eel industry could go forward without detriment to the very valuable trout and salmon fisheries of the region.

The distribution, density and growth of the European eel *Anguilla anguilla* (L.) in the River Thames catchment

by

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Improving water quality in the Thames Estuary since the 1960's has re-opened the Thames Catchment to migratory fish. The extent of recolonisation by the eel is examined, using data from 235 survey sites, compared with limited records of its pre-pollution distribution. Density is highest in the lower parts of the catchment and decreases significantly with increasing distance from the tidal limit. Only a sparse population is found beyond 50km above the tidal limit and artificial stocking is a significant factor in this area. The rate of recolonisation has been slow and neither the annual natural recruitment nor distribution of the pre-pollution stock of the 1800's has been achieved. The future commercial, scientific and conservation values of eels in the Thames and their management is considered.

Age and growth of eel *Anguilla anguilla* (L.) in oligotrophic streams

by

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ABSTRACT

Ages of a sample of 69 eels from two tributaries of the Burrishoole River on the Atlantic coast of Ireland were determined using the burning and cracking technique. Incremental growth rates were found to be amongst the lowest reported in the literature with means per individual ranging from 0.31cm to 2.33cm. The greatest increments in most cases were observed in the first freshwater year, but took place up to age 6 in some individuals. Values of 56 and 60 were calculated for L_∞ for male and undifferentiated eels in the two streams.

INTRODUCTION

Studies of age and growth of eel have been reviewed by Fontenelle (1991). A feature common to all is that the samples have come from relatively rich waters. Vollestad et al (1988) point out that most of the methods of interpretation of eel otoliths are satisfactory for young eels in fast-growing populations but that the outer annuli of old, slow-growing otoliths are frequently obscured. They concluded that these are revealed more clearly by the 'burning and cracking' method than by other techniques.

The Burrishoole system in the west of Ireland (9°55'W 53°55'N) consists of three main lakes of total area 628ha and some 45km of shallow stream. Approximately 32% of the freshwater catchment is covered with coniferous forest. Two of the tributary streams, the Cottage River and the Glenamong River flow into Lough Feeagh (Fig. 1) and are oligotrophic spate rivers prone to flash flooding.

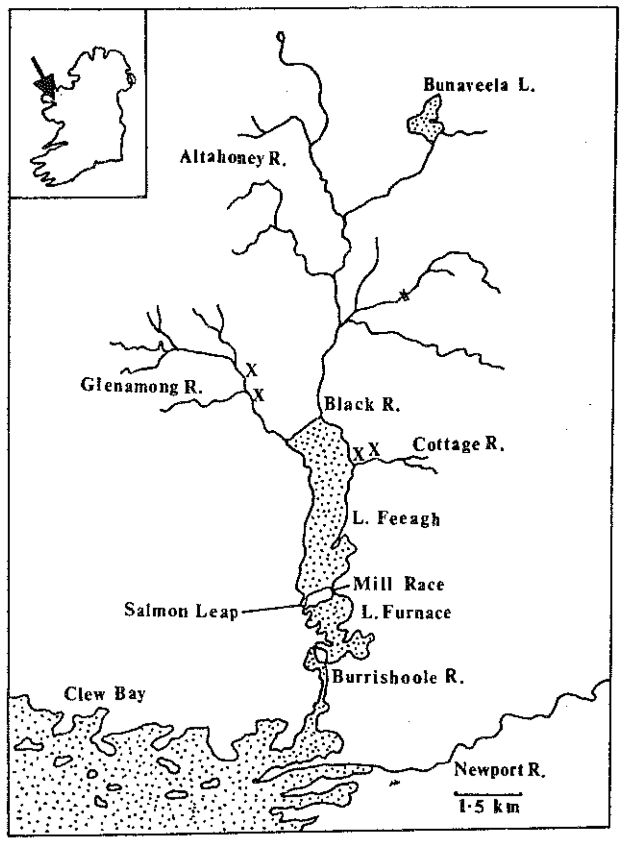

Figure 1: The Burrishoole river system. Eel sampling point marked 'X'.

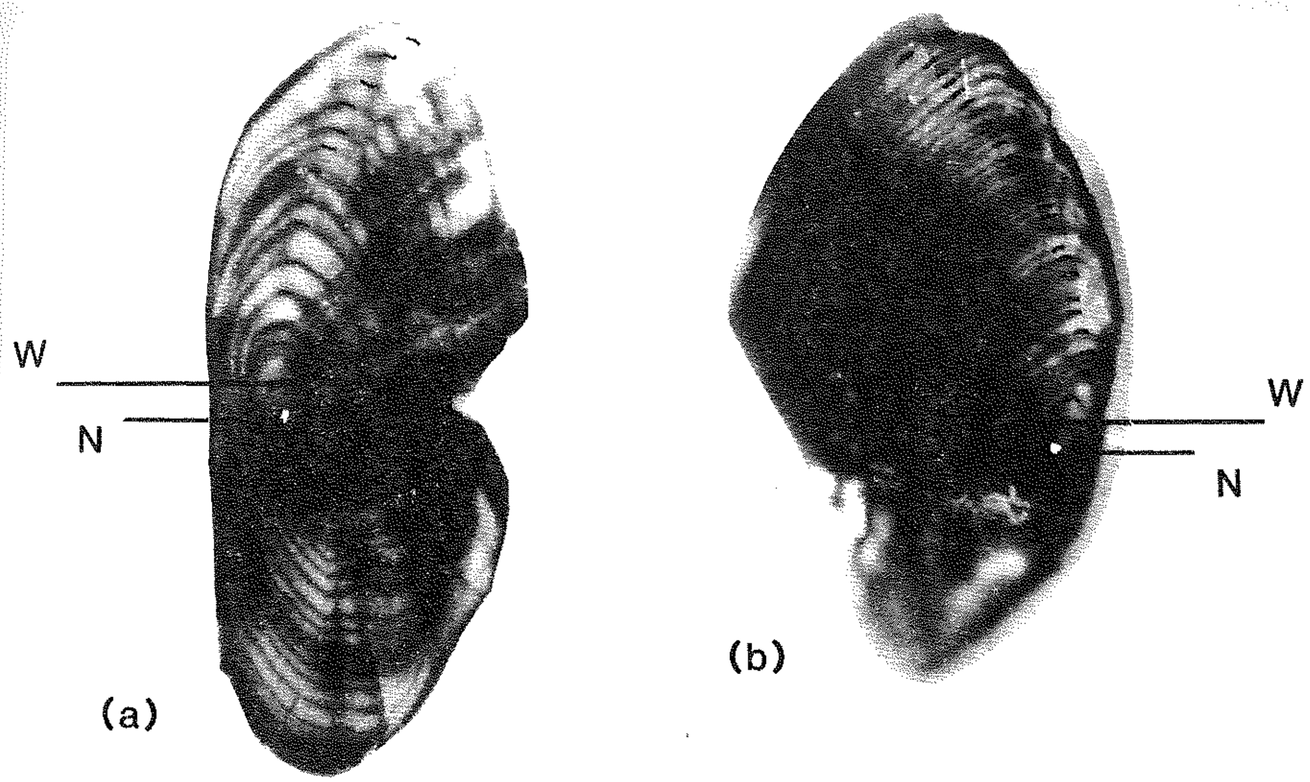

Figure 2: Cottage River otoliths from two eels measuring 33.6cm, ages 13 and 29 years, showing annual rings and points (-) between which incremental measurements were made. N = outer edge of nucleus and W = first winter annulus (age 0).

The Cottage R, 3km in length, flows through an ill-defined valley of blanket peat with some deciduous woodland. Some sheep grazing occurs but this has no evident effect on the river. The water is acid to neutral, moderately buffered (pH 5.8-7.2, conductivity 62-130 uS/cm at 5°C).

The Glenamong is longer, 6.5km, and is bounded to the south by coniferous forestry plantation and to the north by exposed blanket peat; the headquarters all flow through new coniferous forest. The water is more acid than in the Cottage R (pH 4.4-6.6, conductivity 56.0-140.9 uS/cm at 5°C) with acid flush events and high levels of suspended organic solids — both probably resulting from afforestation and severe overgrazing by sheep. The shallow nature of both rivers and large fluctuations in water level subject them to extremes of temperature, falling to winter minima of 0° to 5°C and summer maxima of 17° to 24°C (Poole, unpublished).

This paper presents data on age and growth of eels from these two oligotrophic streams and is the first study of the species from such an extreme of its habitat range.

MATERIALS AND METHODS

Eels were collected from the Cottage R in November and the Glenamong in December 1988 using a back-pack electrofisher (pulsed dc). Samples were taken from four 30m stretches of the Cottage R of mean width 1.5 to 4.6m, depths 0.1 to 0.6m and six 30 metre stretches of the Glenamong 4.9 to 10.3m mean width and 0.2 to 1.5m depth.

The entire catch of 69 eels was examined. Total lengths to nearest mm and weights to nearest 1g and 5g for speciments of less than 100g and 500g respectively were measured. Sex was determined by gross morphological examination of the gonads (Bertin, 1956). Differences between samples were tested by Mann-Whitney U-test.

Otoliths were prepared using the 'burning and cracking' method (Christensen, 1964) and mounted as described by Hu and Todd (1981). The first clearly defined annulus outside the nucleus (taken to mark the end of the glass eel's winter in the estuary) was counted as zero (Fig. 2). Vertical distances between annuli were measured using an eyepiece graticule and ×100 magnification. The ages of the Cottage R eels were determined independently by Poole and by Moriarty.

The first clearly marked annulus was taken to be equivalent to 72mm, the mean length of local estuarine glass eel in the winter of 1987/88 (Poole, unpublished). Assuming isometric growth, values for the annual increments (a) were calculated according to the formula:

$$a = i(L-7.2)/l$$

where i = vertical distance between successive annuli
L = total length of the individual
l = Σi for the individual

Growth was described using the von Bertalanffy (1957) growth equation:

$$l_t = L_\infty(1-e^{-K(t-t_0)})$$

RESULTS

Population parameters

Twenty-seven eels were caught in the Cottage R and 42 in the Glenamong. On the assumption that all eels in the stretches had been caught, population densities ranged from 0.012 to 0.129 per m^2 in the four stretches of the Cottage R and from 0.031 to 0.226 in the Glenamong.

Cottage R eels were smaller, 15 to 34.5cm, than those from Glenamong, 17.1 to 47.0cm. Differences between the means, 27.1 to 28.2cm respectively, were not significant. The value of b in the length-weight relationship $W = aL^b$, for the Cottage R, 3.46, was greater ($p<0.05$) than in the Glenamong, 3.18, indicating increased weight for length above isometric growth.

The ratios of sexually undifferentiated eels to males were significantly different between the streams ($\chi^2 = 7.59$, $p<0.05$). The numbers in each stream were:

	Cottage R	Glenamong R
Undifferentiated	23	23
Male	3	17
Female	1	2

Otolith interpretation

The first Cottage R otoliths were read twice independently with the following results:

		1st reader	2nd reader
	No difference	23, 12 years	23, 12
Difference of	1 year	12,21,10	13,20,9
	2	14,27	16,29
	3	22	19
	4	16	20
	5	19	24

Two of the Cottage R otoliths are shown in Fig. 2. Differences between fast and slow growth are clearly visible. The need in this population for incremental measurement to be made along a curve rather than along a radial line is also apparent.

Growth

Multiple rings were present in a number of the otoliths, making them difficult to interpret. Eight of the 69 were rejected as unreadable. The Cottage R eels were younger, 4 to 29 years, than those of the Glenamong, 5 to 35, means 14.5 and 15.2. Age frequencies are shown in Fig. 3. The one female in the Cottage R measured 28.4cm. The two in the Glenamong were larger and older than the males and undifferentiated ($p<0.05$).

The mean annual growth increments for specimens from both rivers are shown in Fig. 4. The greatest means were in the first year in freshwater (Table 1) and the most rapid growth thereafter took place in years 2 to 6 in the Cottage R and 2 to 5 in the Glenamong. Occasional years of good growth were observed up to year 11 in the Cottage R and to year 14 in the Glenamong (Table 2).

Back-calculated length for age curves showed no significant difference between samples from the two rivers (Figure 5). Values for L_∞, K and t_0 are given in Table 3 using least squares regressions in Ford-Walford plots (Walford, 1946). The values of L_∞ and K were higher and lower respectively when the three females were included in the calculations. These parameters showed a much greater difference in the case of a sample of 73 silver eels from the system.

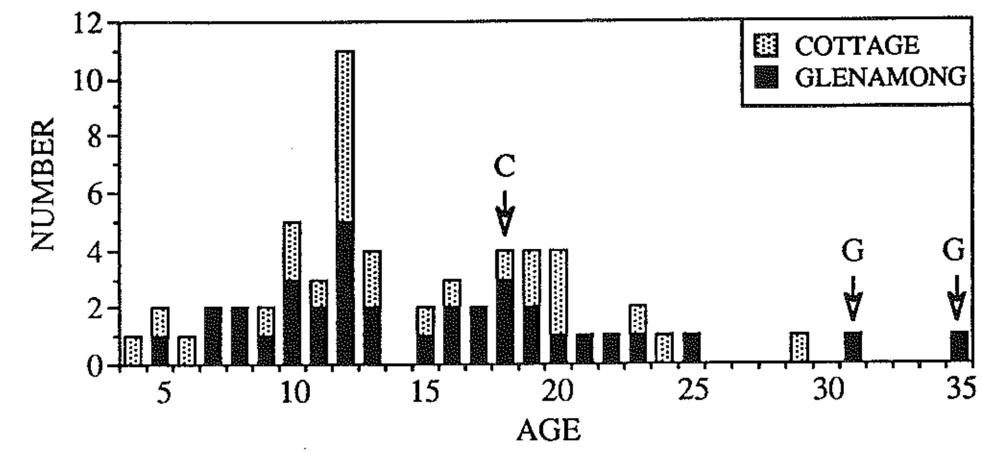

Figure 3: Numbers of eel in year groups: females indicated by 'C' (Cottage River) and 'G' (Glenamong).

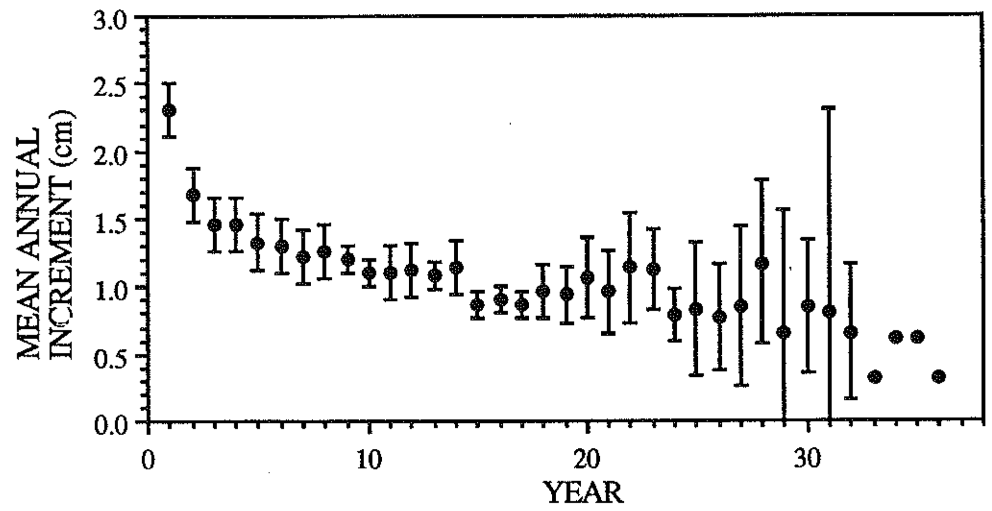

Figure 4: Means (with 95% confidence limits) of back-calculated annual growth increments for Cottage R and Glenamong together.

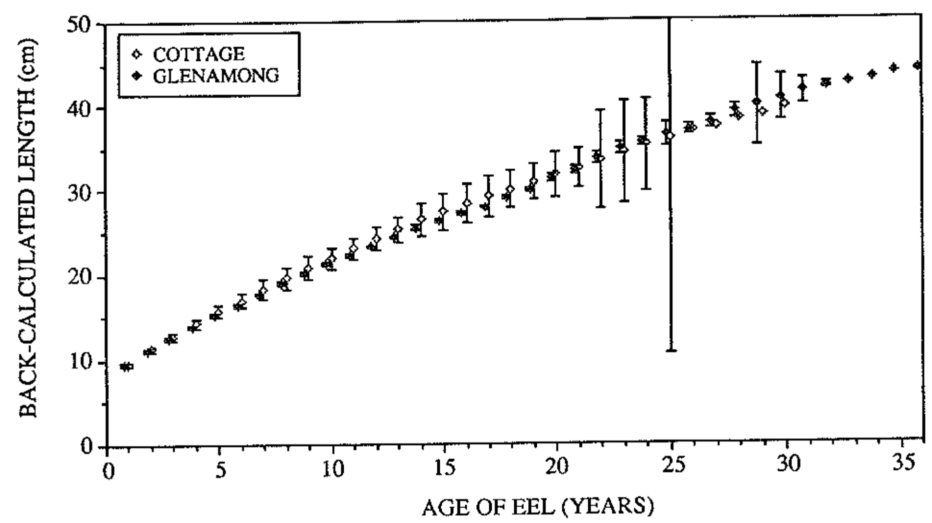

Figure 5: Means (with 95% confidence limits) of back-calculated length at age, points staggered to show overlap.

DISCUSSION

Age determination of the eel has been highly controversial, although some validation of the more popular techniques has been achieved (Vollestad et al., 1988) and determination using the burning and cracking method has been validated under certain circumstances. Little has been published on the growth of the eel in marginal habitats and extreme conditions such as the oligotrophic small streams described in this paper.

Slow growth and high ages characterise the eel population of the two streams studied. The maximum age observed was 29 years compared with 14 years in the Irish River Barrow (Moriarty, 1983), 18 in the English Lake Windermere (Frost, 1945) and 20 in a small Danish stream (Rasmussen and Therkildsen, 1979). Values of L_∞ were lower than recorded previously (Nagiec and Bahnsawy, 1990) but the samples used by other authors were of larger eels, including substantial numbers of females.

The eel populations in the two streams were unexploited and the biggest males were similar in size to male silver eels captured in the same system. Therefore it is reasonable to assume that eels remain in the streams until they attain maturity. From this it appears that maturity is associated with size rather than with age.

ACKNOWLEDGEMENTS

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Table 1: Frequencies of increments of given size in first year and for whole sample.

Increment size (cm)	COTTAGE R		GLENAMONG R	
	first year	all years	first year	all years
0 -0.4	0	0	0	17
0.5-0.9	0	143	0	164
1.0-1.4	1	104	0	177
1.5-1.9	9	64	9	66
2.0-2.4	7	30	7	36
2.5-2.9	2	16	9	17
3.0-3.4	4	6	4	9
3.5-3.9	1	1	0	0
4.0-4.4	0	0	0	1

Table 2. Number of speciments in which greatest increment took place in given freshwater year and maximum size (cm) of increment.

	COTTAGE R		GLENAMONG R	
Year	number	max size	number	max size
1	14	3.5	17	3.4
2	4	2.8	4	3.1
3	0		4	4.3
4	1	2.9	1	3.0
5	2	2.9	2	3.4
6	1	2.9	0	
8	1	2.9	1	2.8
11	1	3.0	0	
14			1	2.5

Table 3. Values for L_∞, K and t_0 for yellow eels (present study) and for silver eels from The Burrishoole R (farther downstream in the system) in 1988.

Cottage R	(23 male, 1 female)	61	0.03	−4.3
	(23 male)	60	0.03	−4.2
Glenamong	(28 male, 2 female)	70	0.02	−5.2
	(28 male)	56	0.02	−4.5
Burrishoole	(29 male silver)	66	0.04	−3.4
	(44 female silver)	150	0.01	−4.2

Deflecting eels from water inlets of power stations with light

by

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ABSTRACT

Investigations at thermal power stations in The Netherlands have shown that eels and other fish are caught on the cooling water screens and end up in containers along with debris. In the last few years several hydroelectric power stations came into operation on Dutch rivers. We found that eels can be damaged by passing through the turbines during downstream migration. Experiments aimed at finding a way of preventing fish from entering cooling water intakes have been carried out with light, air bubbles and electrical screens. The experiments with light were successful. Eels showed a clear avoidance reaction to light in both laboratory and small river experiments. Light barriers might therefore be effective in deflecting eels from water intakes of both thermal and hydroelectric power stations.

Key words: eel; power stations; light; deflecting methods; mortality

INTRODUCTION

Power stations use large amounts of water from rivers and lakes. Thermal power stations need water, about 40 m^3/s per 1000 MWe, for cooling the condensers. Fish in the cooling water flow are caught on the cooling water screens. Generally they are collected in containers and die. At hydroelectric power stations fish mortality occurs by passage through the turbines. KEMA has investigated these fish-related problems at thermal and hydroelectric power stations (Figure 1) and developed methods of minimizing them.

Of the fish caught at six thermal power stations on the rivers Rhine and Meuse, 63-96% were juveniles of several species (Hadderingh et al., 1983), this being because of their low ability to resist the cooling water flow. The number of eels per year ranged from only 224 at the Maas power station to 50,000 at the Amer power station. Much higher numbers, about 250,000 eels per year, are caught at a power station cooling on lake Bergum (Hadderingh, 1982), yellow eels being more numerous than silver eels.

Passage and mortality of eels at hydroelectric power stations were investigated during their seaward migration in the autumns of 1988 and 1990. Some hundreds of silver eel may pass the turbines in one night at hydroelectric power stations on the river Meuse. Mortality of eels caused by turbine passage ranges between 5 and 25%, depending on the flow through the turbines and the type of turbine. Analysis of these data is still going on.

Several investigations have been carried out by KEMA to develop fish barriers to reduce the concentration of fish at intakes of power stations. The first experiments concerned mainly the catch reduction of small 0+ fish of different species of length between 5 and 10cm. Illumination of the cooling water intake of the Bergum power station showed a clear reduction in catch of these 0+ fish and also of eels (Hadderingh, 1982). Experiments with air bubbles (Hadderingh et al., 1988) and electrical screens (Hadderingh and Jansen, 1990) were not very promising, however.

A new need to develop fish barriers resulted from the construction of three hydroelectric power stations in the rivers Meuse and Rhine between 1986 and 1990. At hydroelectric power stations in Germany (Von Raben, 1955) and Sweden (Montén, 1985) considerable mortality levels were found among silver eels migrating downstream. In earlier years, Van Drimmelen (1951), Lowe (1952), Bräutigam (1961, 1962) and Hölke (1964) already used light to raise the commercial eel catch based on the avoidance reaction of eels to light. On the basis of this information, several laboratory and field experiments were carried out to study the reaction of eels to light in order to develop a functional light barrier.

This article presents a broad overview of the results of laboratory and field experiments conducted between 1986 and 1990. Some of the experimental results will be published in more detail elsewhere.

MATERIALS AND METHODS

Laboratory experiments

Experiments in still water were carried out in a tank with dimensions of 160 × 150 × 55cm (Figure 2). The tank, filled with tap water to a level of 20cm, was divided into two equal compartments by a partition placed 15cm above the bottom of the tank. One compartment was kept dark by a cover, the other was illuminated

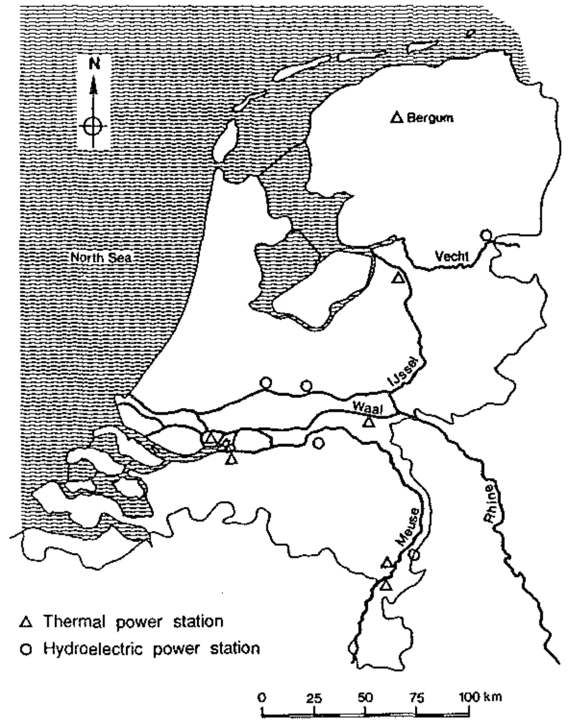

Figure 1: Map of The Netherlands with thermal and hydroelectric power stations located on the rivers Rhine, Meuse and Vecht and on lake Bergum.

by lamps suspended above the water surface. Five silver eels, released in the tank, could choose between the dark and the illuminated compartment after an adaptation time of 30 minutes. The reaction of the eels was determined for different types of lamps and illumination levels. The distribution of the 5 eels was registered every 5 minutes during a period of 30 minutes. This procedure was carried out three times for each illumination level; each time a new group of 5 eels was used. For the normal distribution (0 lux) five experiments were conducted. In the total of 32 experiments 160 eels were used. Recording of the behaviour was performed with a video camera and recorder.

The silver eels had been caught by a commercial fishery on the river Meuse the night before the experiment was conducted. The average length of the eels was 37 cm (range 29-55cm).

Experiments with running water were carried out in a variable-speed flume (Figure 3). The design was based on the flume developed at the Marine Biology Unit at Fawley (UK) (see also Turnpenny and Bamber, 1983). The flume was used with a test section 630cm long and 132cm wide, filled to a depth of 26cm with tap water. Silver eels, average length 48cm (32-72cm), were caught in November 1990 with nets in the rivers Meuse and Vecht. The eels were held in tanks in the laboratory under a controlled natural photoperiod till they were used in the experiments in March/April 1991. One eel was released at a time at the upstream side of the test section between gratings 1 and 2 (see Figure 3). After an adaptation time of 2 minutes the eel could swim downstream through a small gate which was opened in the centre of grating 2. At the downstream side, a partition divided the flume in one dark and one illuminated compartment. The illumination was performed by an incandescent lamp (tungsten filament, continuous spectrum) placed above one of the two compartments. The eels were tested at water velocities between 11 and 45 cm/s and illumination levels of 1 and 10 lux in the water. To prevent bias entering into the results of the experiments the dark and the illuminated compartment were defined at random.

Field experiments at Bergum power station

In 1987 experiments were carried out with light barriers at Bergum power station. Many eels are entrapped in the cooling water inlets of this power station as was found in earlier studies (Hadderingh, 1982). Therefore Bergum power station offered a good opportunity to study the reaction of eels to light. The experiments were not meant to save eels from entrapment because a bypass is not present at this power station. Bergum power station consists of two conventional units of 320 MWe each and is situated at lake Bergum, a shallow eutrophic lake with a large fish population. The lake water is very turbid with a Secchi disk value of about 25cm.

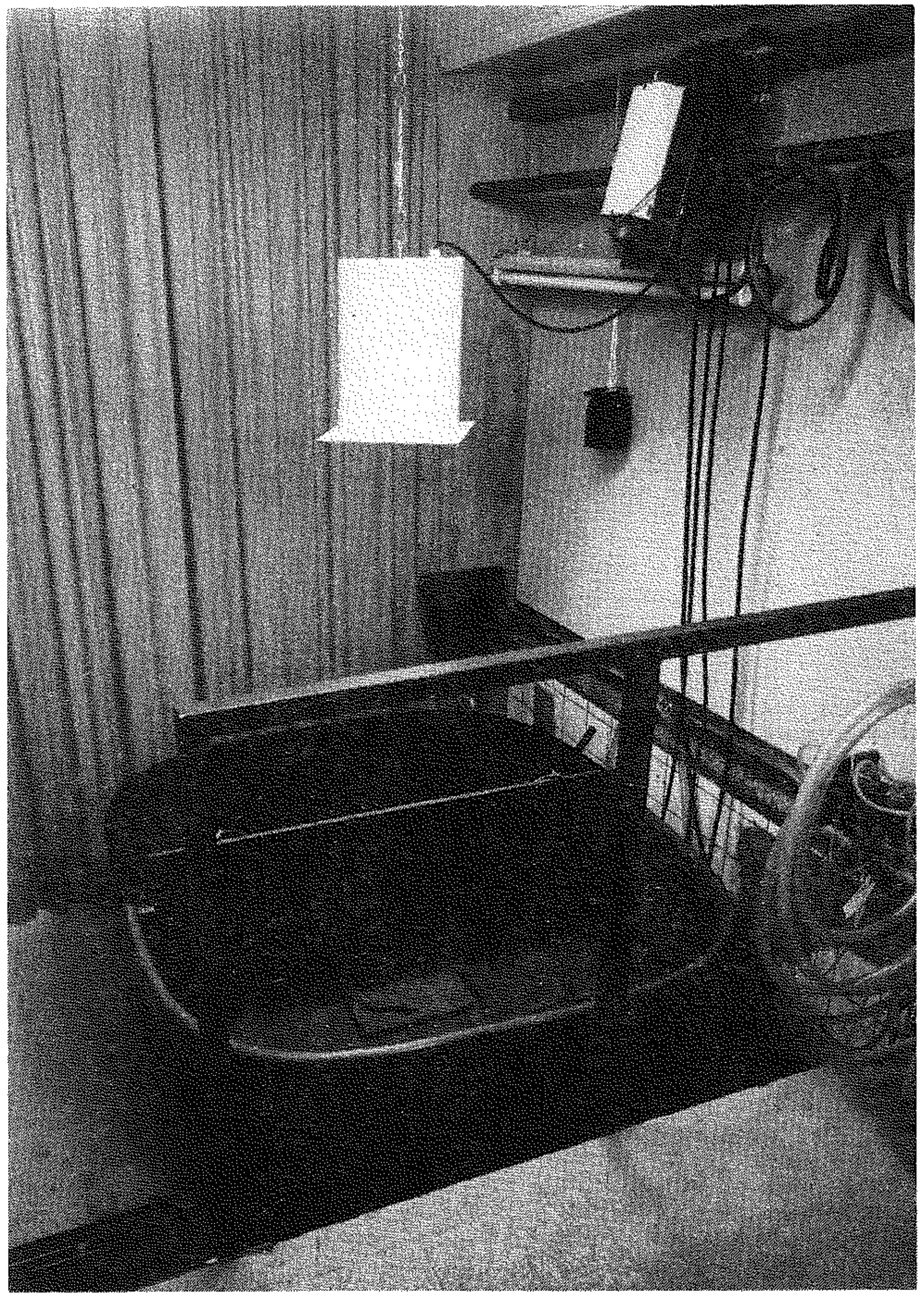

Figure 2: Experimental design to investigate the reaction of silver eel to light in still water.

Cooling water is taken in by two inlets, one for each unit. The maximum cooling water flow per unit is 14 m^3/s. Fish are caught on rotating drum screens with 5mm square meshes.

A light barrier was mounted 5m in front of the cooling water inlet (Figure 4). One of the inlets was illuminated, the other was kept dark. Eels deflected from the illuminated inlet had the opportunity of swimming into the dark inlet. One experiment was conducted with high-pressure mercury lamps 1m above the water surface (Figure 4A). In this experiment the illumination was changed from inlet every next night. In a second experiment, a combination was used of high-pressure mercury lamps above the water surface and incandescent underwater lamps (tungsten filament, continuous spectrum) on the bottom of the intake of unit 1 (Figure 4B). The effect of the illumination was determined by comparing the average eel catch at the illuminated and at the dark cooling water inlet. The deflection rate has been calculated as deviations from an assumed 50:50% distribution of the eel catch over the units 1 and 2.

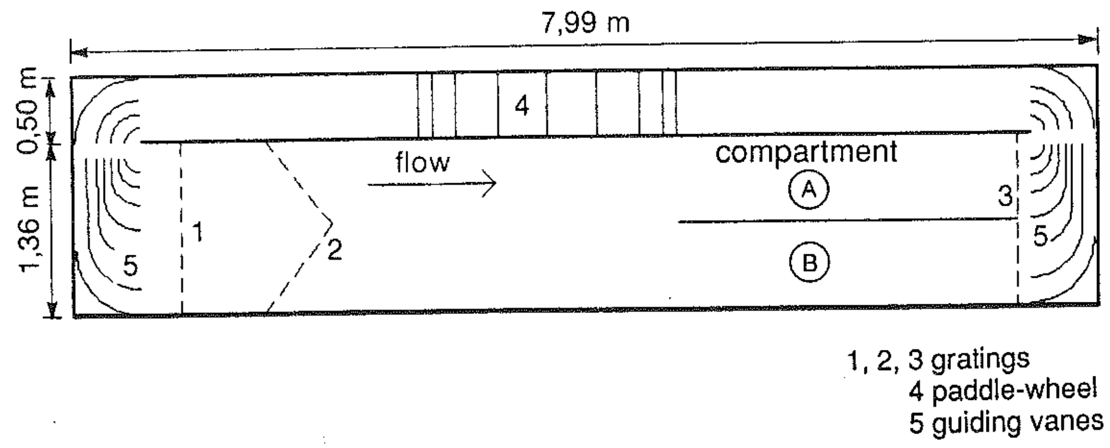

Figure 3: Upper view of the flume for light experiments.

Experiments at the De Haandrik hydroelectric power station

This power station has a capacity of 0.1 MWe and is equipped with a Kaplan turbine with a vertical shaft. The river flow ranged between 8.6 and 20.4 m^3/s (average flow 13.8 m^3/s). The flow through the turbine was 6.7 m^3/s; the surplus of the river flow went over the weir next to the power station. Secchi disk value ranged between 30 and 125cm (average 74cm). To deflect eels from the power station towards the weir a light barrier was placed at 4m in front of the water intake of the power station over a width of 4.5m (Figure 5). The barrier consisted of a row of 9 incandescent lamps of 200W each laid on the bottom (2.6m water depth) and 2 high pressure mercury lamps of 2000W each at 1.5m above the water surface. The average water velocity at the light barrier was 59 cm/s. The effect of the barrier was determined by counting the number

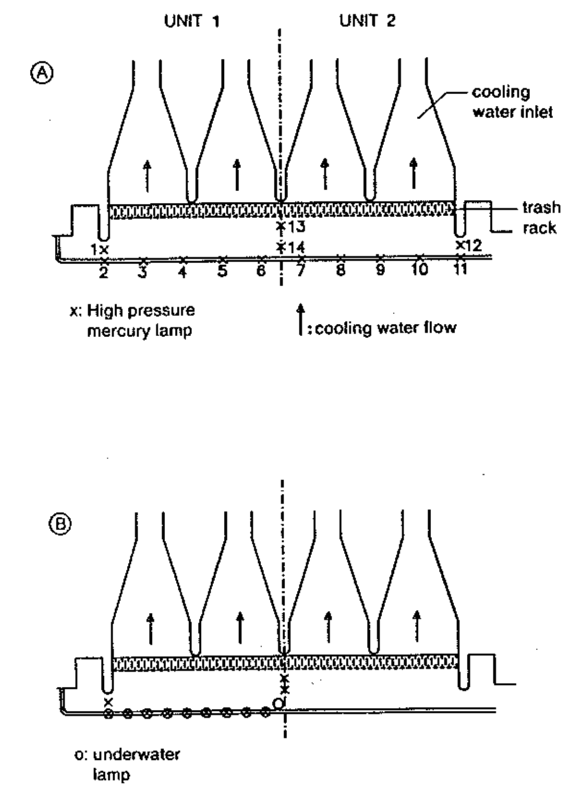

Figure 4: Light barriers for the cooling water inlets of Bergum power station. A — lamps above the water surface, B — lamps above and under water.

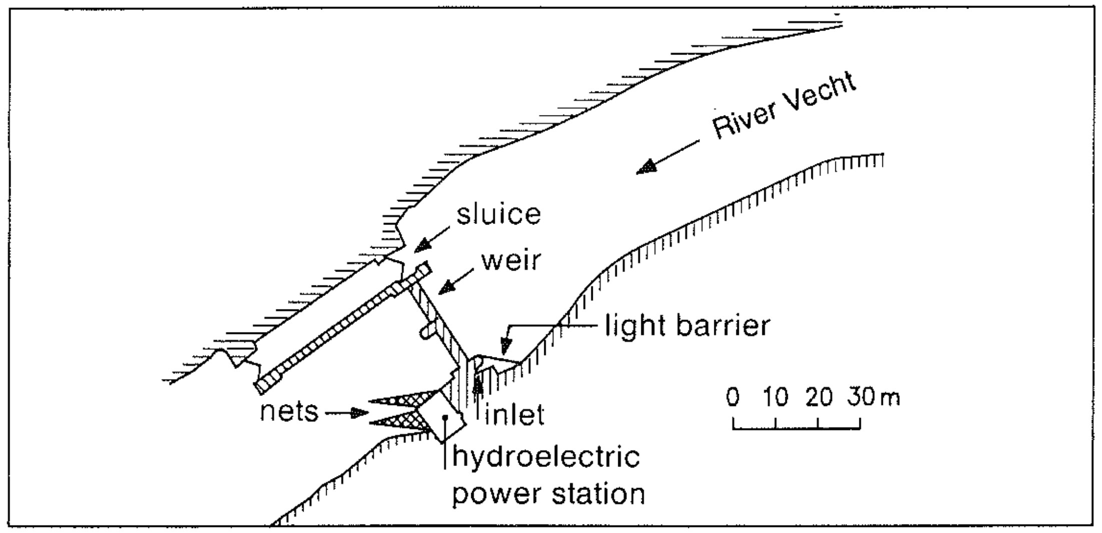

Figure 5: De Haandrik hydroelectric power station with light barrier in front of the inlet.

of eels passed through the turbines on dark and illuminated nights during a series of 12 nights between 26 September and 8 October 1988. It was not possible to collect the eels passing the weir.

Experiments at commercial eel fisheries

Two experiments with light barriers were performed in the river Regge (1988 and 1989) and one in the river Vecht (1990). Both rivers are relatively small with a maximum depth of about 3m and a width of about 30m. The average Secchi disk value was 70-75cm in the river Regge and 100cm in the river Vecht. Water velocity was not measured regularly but varied strongly between circa 0 and 60 cm/s depending on the amount of rainfall. The silver eel fishery in these rivers is conducted by closing the river with nets from shore to shore. In the Regge this is done by a row of fyke nets, in the Vecht by a combination of fyke nets and a barrage net (see Figure 6).

A light barrier, consisting of a row of incandescent lamps of 200W each, was laid on the bottom over about two thirds of the river width as shown in Figure 6. Experiments were carried out during the major part of the migration period for silver eel in late summer and autumn. During the fishing period each dark night was followed by an illuminated night. The effect of the barrier was determined by comparing the average eel catch behind the barrier during dark and illuminated nights.

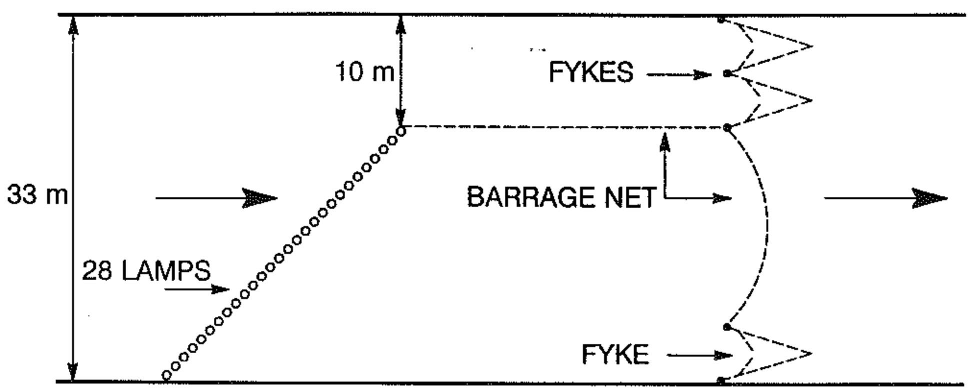

Figure 6: Commercial fishery with light barrier in the river Vecht.

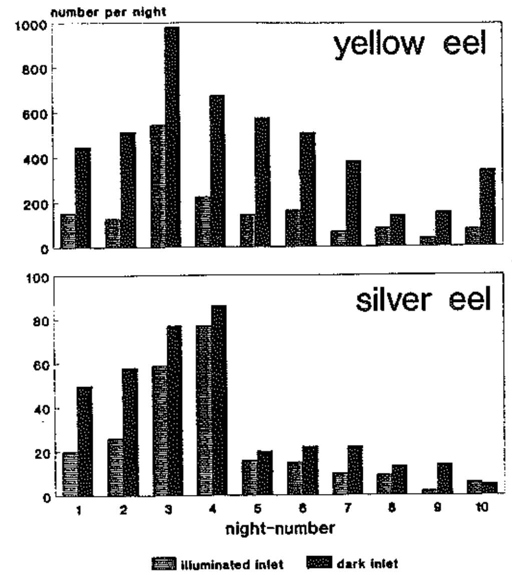

Figure 7: Numbers of yellow and silver eels caught in the illuminated and dark cooling water inlets of Bergum power station, lamps above and under water, October 1987.

RESULTS

Laboratory experiments with still water

Table 1 presents the average distribution of eels in the dark and illuminated compartment of the tank. The average number of silver eels in the dark compartment is at least 10 times higher than in the illuminated one. The results clearly indicate the preference of eels for a dark environment. The slight increase in the average number of eels in the dark compartment at higher illumination level seems not to be significant. Differences in distribution between the the lamp types are not significant either.

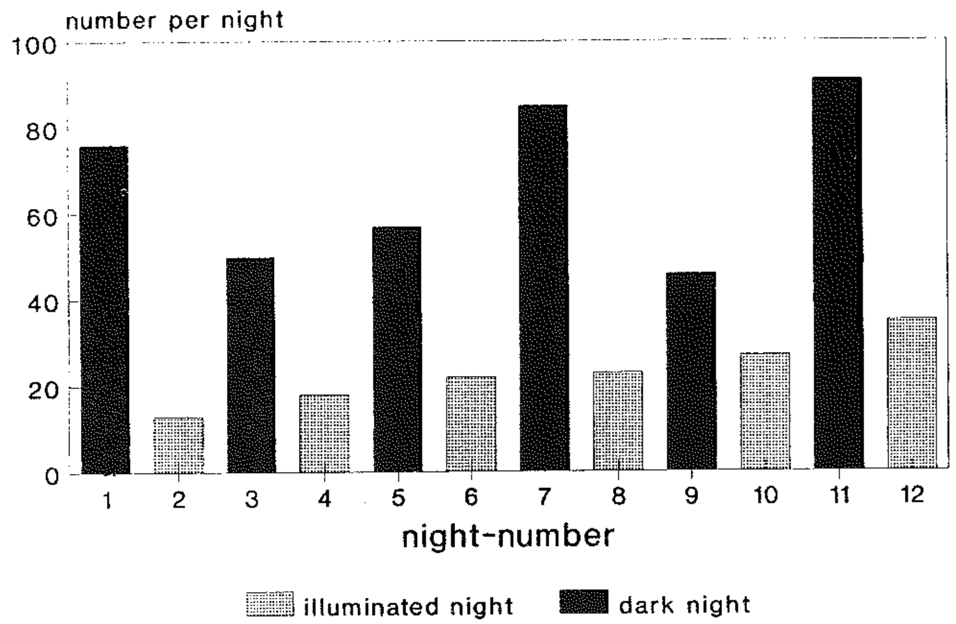

Figure 8: Numbers of eels passing through the turbine during nights with and without illumination of the water inlet of the De Haandrik hydroelectric power station, September/October 1988.

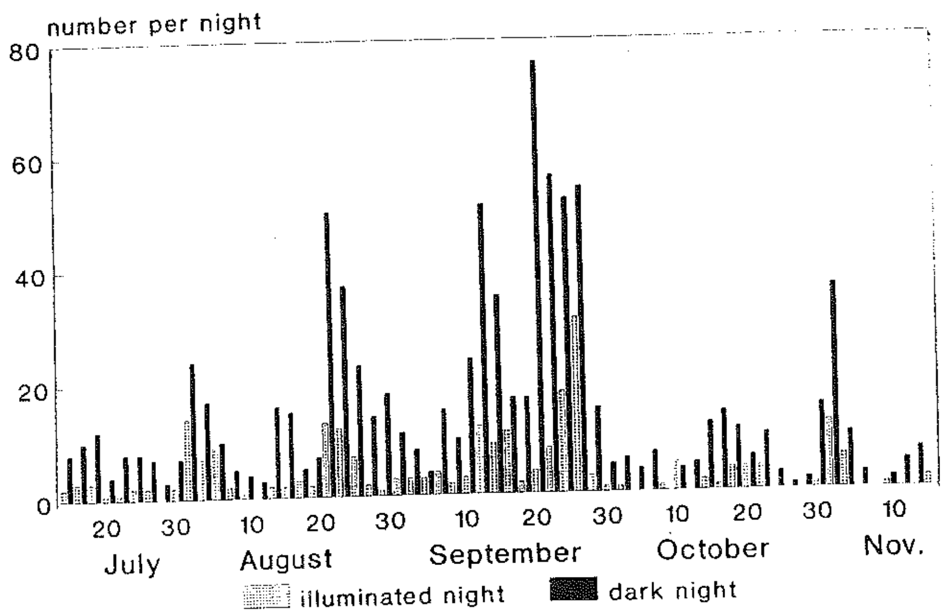

Figure 9: Numbers of eels caught behind the light barrier on dark and illuminated nights, river Vecht, 1990.

Laboratory experiments with running water

The results of the experiments in the flume, presented in Table 2, demonstrate the eel's clear avoidance reaction to the illuminated compartment. The percentage of the eels choosing the dark compartment ranged from 64% (1 lux, 35cm/s) to 90% (10 lux, 11cm/s). Differences between these percentages were not significant (Chi-square test, $\alpha = 0.05$). This suggests that water velocities between 11 and 45cm/s and an illumination between 1 and 10 lux result in a similar avoidance reaction.

Experiments at Bergum power station

The results of the light experiments are presented in Table 3. The numbers of yellow and sliver eels caught in the illuminated and dark inlets during the 10 nights are given in Fig. 7. Illumination with lamps above the water surface resulted in a negligible deflection of eels by the light barrier: 0% for yellow eels and only 6% for silver eels. The combination of lamps above and under water gave better results with a deflection of 51 and 25% for yellow and silver eels respectively (see also Figure 7). The difference between the numbers of eels in each of the two inlets seemed to be significant after the Wilcoxon matched-pair signed-ranks test. The results of these experiments indicate that, because of the high turbidity of the lake water, the use of underwater lamps was necessary.

Experiments at the De Haandrik hydroelectric power station

In the illumination experiment at "De Haandrik" 543 eels were caught at the outlet of the power station. The average length was 45cm (range 24-80cm). The majority were silver eels (92%). The results of the experiment are presented in Figure 8. The average number of eels on illuminated nights (23) was significantly lower (after Wilcoxon) test, $\alpha = 0.01$) than on dark nights (68). The reduction of the numbers passing through the power station was 66%.

Experiments at commercial fisheries in rivers Regge and Vecht

A summary of the results of the illumination experiments in the rivers Regge and Vecht is presented in Table 4.

Deflection percentage of eels at full lamp capacity (10 lux) ranged from 73% in the river Vecht to 85% in the river Regge (1988). The illumination level seemed to have a clear influence on the deflection rate: in the river Regge the deflection percentage decreased from 76% at 10 lux to 30% at 0,6 lux.

Figure 9 gives the eel catches behind the light barrier in the river Vecht during the 126 nights of the experiment. The number of eels caught on dark nights is consistently higher than on illuminated nights. The strong fluctuations in the eel catches are related to changes in moon phase and river flow.

DISCUSSION

In the laboratory experiments with still water, a strong avoidance reaction to light was observed among silver eels. The three lamp types led to no significant differences in their reactions. Maximum response of eels' photosensitive receptors has been found at 500nm for twilight receptors and at 560 nm for daylight receptors (Protasov, 1970). Both wavelengths are present in the continuous spectrum of the incandescent lamps and as low peaks in the discontinuous spectrum of the sodium lamp. The discontinuous spectrum of the mercury lamp lacks a 500nm peak but a high peak of 550nm is present. Despite these differences between the energy-spectra of the lamps, differences in reaction were not found in the laboratory experiments. This suggests that all three lamp types are suitable for repelling eels. Patrick et al. (1982) found a strong avoidance reaction to white strobe light (400-570nm) amongst yellow eels. Red strobe light (600 > 700nm) led to no avoidance reaction.

In the laboratory experiments, both with still (Table 1) and running water (Table 2), no differences in reaction level could be found between different illumination levels. In the field experiment on the river Regge (1989) the deflection rate decreased from 76% at 10 lux to 30% at 0.6 lux (see Table 4). This discrepancy might be attributed to the fact that under field conditions the eels must be deflected a considerable distance, about 10 to 15 metres, away from the light barrier to reach the dark area of the river (see Figure 6). In this situation the chance of passing the light barrier is highest at the lowest light level of 0.6 lux, because the illuminated zone is relatively narrow.

The results of the field experiments indicate that when migrating downstream, eels can be deflected successfully with a light barrier. Mortality of eels at power stations might be minimized by using this method.

Essential for the successful use of light barriers is a bypass into which the eels can be deflected. Without a bypass the eels will repeatedly try to swim across the barrier in a downstream direction and will finally enter the water intake. At hydroelectric power stations a weir or fish ladder next to the power station can be used as bypass. For thermal power stations situated on rivers, a barrier might be successful if it could be installed along the shoreline where the cooling water is extracted from the river. In this case the eels can be deflected along the river itself. At thermal power stations situated on lakes, eels might be deflected towards a pipeline discharging into the cooling water outlet area. Another solution to the eel problem at thermal power stations is a functional fish-transport system which would lead the entrapped fish back to the river or lake.

Few applications of light barriers for deflecting eels from power stations are published. Berg (1985) experimented with underwater lights at a hydroelectric power station in the river Neckar, a tributary of the river Rhine. In this case the light barrier was not successful, probably because of the short distance between the lamps and the intake, and the low light level.

The experiments in rivers Regge and Vecht demonstrated the usefulness of a light barrier in commercial fisheries. There is a problem in these fisheries caused by the clogging of the nets with floating debris and plant material especially at high water velocities. In these circumnstances, application of a light barrier offers a good alternative to the barrage net. Another advantage is the free passage for other migrating fishes.

It can be concluded that the application of a light barrier offers good possibilities for both deflecting eels from water intakes at power stations and for improvement of commercial eel fisheries. Saving eels at power stations seems to be conflicting with catching eels by commercial fisheries. This is not the case however with a good fisheries management where the catch is held in balance with the population.

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Table 1. Average number of silver eels in the dark and illuminated compartments at four illumination levels and three types of lamps.

compartment	0 lux control	0.1 lux	8 lux	55 lux
		incandescent		
dark	2.6	4.6	4.6	5.0
illuminated	2.4	0.4	0.4	0
		sodium		
dark	2.6	4.6	4.9	4.9
illuminated	2.4	0.4	0.1	0.1
		mercury		
dark	2.6	4.7	4.9	4.9
illuminated	2.4	0.3	0.1	0.1

Table 2. Choice between a dark compartment and an illuminated compartment made by silver eels while swimming downstream.
***(n = number of eels tested)**

water velocity cm/s	illumination 1 lux		illumination 10 lux	
	% eels in dark	n*	% eels in dark	n*
11	79%	42	90%	20
22	86%	22	—	—
35	64%	22	—	—
45	76%	21	75%	24
average	76%		82%	

Table 3. Results of the illumination experiments at Bergum power station in 1987.

number of lamps above surface	number of lamps on bottom	number nights	category eel	percentage deflection	mean length	total number eels
		illumination above water				
8 × 2000W	—	18	yellow	0%	22.8cm	9348
"	—	18	silver	6%	38.2cm	1599
		illumination above and under water				
12 × 2000W	10 × 100W	10	yellow	51%	22.1cm	6030
"	"	10	silver	25%	41.2cm	610

Table 4. Results of illumination experiments at commercial fisheries in the rivers Regge and Vecht. Average numbers through light barrier on dark nights (Na) and illuminated nights (Nb). *measured 1.5m in front of the barrier, 1m above bottom.

river	year	illumination level*	number through light barrier Na	Nb	percentage deflected	number nights	average length (cm)
Regge	1988	10 lux	50.7	7.4	85%	52	38.5
Regge	1989	10 lux	13.0	3.2	76%	12	39.2
		4 lux	26.0	8.8	67%	14	41.1
		0.6 lux	13.6	9.7	30%	12	37.4
Vecht	1990	10 lux	14.7	4.0	73%	126	45.5

Growth of eel in a mesoscale experiment

by

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ABSTRACT

Seven thousand eels were cultured in nine tanks at three constant temperatures over the period August 1988 to September 1990. The growth rate was low and not directly correlated to temperature. One explanation is that experimental conditions were not optional, for example the manual feeding was too restricted in time and the eels were infected with gill parasites, *Pseudodactylogyrus anguillae*. An additional and important factor is that in the almost ungraded populations small yellow eels were mixed with increasing fractions of males changing to the nongrowing silver eel stage.

Sampling from these mesoscale populations did not give completely representative results. Less than 100 specimens per sample overestimated mean weight, but probably a relevant sample size would be empirically revealed in each single culture design.

These ungraded eel populations developed into bimodal length frequency distributions, with a lower mode corresponding to slow growing eels and an upper mode dominated by males with declining growth.

Some females seemed to change from slow growers to fast growers towards the end of the experiment, while the growth of many initially fast growing males declined and stopped at 35-45 cm. The suggested connection between growth pattern and sex should be more thoroughly investigated. Large scale tagging and marking are suggested as tools in further studies on growth patterns. Group marking with coloured spots is most promising for small size-classes (10-20 cm) in early size distributions. PIT-tags may be introduced at about 20 cm length. Jaw-tags are only recommended for eels greater than 35 cm.

INTRODUCTION

There is an expanding market for commercially farmed eels, both silver eels for direct human consumption and fingerlings for restocking purposes being in demand. In the latter case, potential females are greatly preferred, at least in Scandinavia, since they grow larger.

Historical studies of gonads have revealed that the tissue is undifferentiated until the eel reaches a length of 15-25 cm (Kuhlmann 1975). Colombo et al. (1984) also suggested that the testis-like gonad of yellow eels is a primitive and possibly reversible gonad which differentiates completely during the change to the silver eel phase. Investigations using cytochemical methods or visible genetic markers have so far failed to validate an agreement between phenotypically and genotypically expressed sex (Passakas and Tesch 1980, Park & Grimm 1980, Wiberg 1983, Sola et al. 1984). Because of this and the occurrence of remarkably skewed sex ratios of eels both in natural waters (D'Ancona 1957, Penaz and Tesch 1970, Parsons et al. 1977) and in eel culture (Egusa 1970), the possible influence of environmental factors on sex determination and differentiation have been discussed (c.f. Beeckman and Ollevier 1987). Culturing experiments under controlled conditions have been proposed as a possible approach in the further investigations (op. cit.).

Growth of eels in culture has been studied in several experiments with different aims. Some studies have been designed to reveal optimum temperatures (e.g. Kuhlmann 1979), optimum nutrient composition (e.g. Degani et al. 1985, Degani 1986, Degani et al. 1986b) or optimum feeding regimes (e.g. Seymour 1989). Growth measurements have also been used to compare rearing at different population densities (e.g. Seymour 1984), sometimes considering concentrations of oxygen and ammonia (e.g. Degani et al. 1985). Sadler (1981) used growth rate as an effect parameter in his study on sublethal toxicity of ammonia. It was observed early on that eels in culture displayed extreme individual growth variations compared to other fish species (Koops 1965, Meske 1969, Kuhlmann 1979). Most growth studies were performed with glass eels or newly pigmented elvers. The experiments usually varied in duration from a few weeks (Seymour 1989) up to one year (Degani et al. 1986a). As a consequence of these short term experiments, growth differences related to sex or final sex ratios have only occasionally been dealt with (Kuhlmann 1975, Knights 1982, Koops and Kuhlmann 1983).

The present study is part of a longterm experiment, aimed at testing whether the sex differentiation of eels *Anguilla anguilla* (L.). is influenced by water temperature. This first paper focuses on growth results, different ways of expressing growth and sources of error when sampling for length and weight. Finally length frequency distributions, taggings and markings are discussed as tools for illustrating growth patterns in populations of eels with restricted size culling.

MATERIAL AND METHODS

Glass eels caught in the English River Severn (Bristol Channel Fisheries Ltd) were imported by a commercial Swedish eelfarm (Lyckeby Fiskodlingar AB) in April 1988. During and after the required period of quarantine the eels were cultured at about 25°C. In July an as yet ungraded fraction was available for delivery and stocking at the Institute of Freshwater Research, Drottningholm. At that time the elvers were already pigmented and the mean length and weight was 11.7 cm (ranging between 7 and 21 cm) and 2.5 g respectively.

The temperature in the transport tank was 17°C at arrival. In the laboratory nine tanks were stocked with about 780 elvers each. The central water supply was drawn from the bottom water in Lake Mälaren and pumped through an aerated (continuously washed) sand filter. It had an initial ambient temperature of 19°C. The nine rearing tanks were equally grouped in three recirculating units. During the first two weeks the temperatures in the units were adjusted to 17 (Tank 1-3), 20 (Tank 7-9) and 26°C (Tank 4-6) with a battery of thermostats for laboratory use. With some exceptions, during short term technical failures, the experimental temperatures (daily measurements) were kept within ±0.3°C deviation from the intended levels. Within each recirculating unit the waste water from three rearing units was mixed and 30 to 90% was recirculated during the experimental period. The total volume per temperature unit was 4.35 m^3 and the supply of new lake water to each system varied between 0.3 and 0.9 m^3/hour, which resulted in a renewal time of 4.7 to 14.2 hours or 1.7 to 5.1 times per 24 hour. Even though water flows changed, the same variation was introduced simultaneously for each of the three temperature regimes.

The eels were fed manually twice daily from Monday to Friday and once daily at weekends during 1988 and 1989. From December 1989 to January 1990 one Touch-Feed-apparatus was introduced to each rearing tank. At the beginning of the experiment the eels were already adapted to a granulated dry feed, (Lactamin Start, 0.8-1.4 mm), and this feed was used for the smallest eels throughout the entire experiment. When the mean weight reached about 5 g, the granulated feed was mixed with pellets with a diameter of 1.5 mm and later 3 mm pellets (Lactamin Extra) were introduced. The daily amount fed varied between 0.3 to 1.7% dry feed weight per fresh weight biomass of the eels (monthly means). It was adjusted for each temperature in order to allow for small amounts of uneaten food. This was subjectively recorded on a daily basis, when faecal matter and uneaten food was removed with a manually controlled siphon.

The water in each tank was aerated with compressed air. The oxygen concentrations in the tanks were monitored three to five times a week, with YSI Model 54 Oxygen meter, and monthly means in surface water were 7.8-9.1 (17°C), 7.9-8.6 (20°C) and 6.1-7.5 mg/l (26°C), respectively. Water samples were taken 1-5 times a month in the rearing tanks as well as in the central water supply. The following parameters were monitored; pH (pH-meter E603, Metrohm Herisau, with Ross Combination electrode), conductivity (Conducto-meter E587, Metrohm Herisau), nitrite (Aquamerck 11117, Test kit) and ammonium (Aquamerck 11158, Test kit). In order to relate water quality variables to eel population variables the former were expressed as monthly median values (Table 1.).

The tanks were emptied of water once a month. When the eels were crowded on the bottom, repeated dip-netting was performed until the sample size reached about 100-150 eels per tank. These were anaesthesized using 0.12 g benzocaine/l of culturing water before being measured and weighed individually. The remaining eels were weighed in bulk, with the exception of May 1990 when all eels were sampled and measured and weighed individually. On five other occasions the total numbers of eels per tank were counted.

The presence of dead or dying eels was noted daily, and their length and weight immediately taken. Four months after the start of the experiment a restricted system of grading was introduced. Some of the largest individuals were simply removed from the experiment and killed after being anaesthesized. In addition to the normal measurements of length and weight, a range of characteristics (including sex), which are not thoroughly discussed in this paper, were also recorded for these specimens.

In January 1989 some eels were individually jaw-tagged with the French Marque Barettes used by e.g. Berg (1986) and described by Nielsen (1987). Tagging continued throughout the experiment. In addition an increasing number of individuals could be recognized due to e.g. well defined damage of fins and/or deviating pigmentation (bright or dark spots). In total 180 jaw-tagged and 216 otherwise recognized eels were observed 2-24 times during the experiment. Some tests with other tagging and marking methods were also performed, for example visible implants (VI, Haw et al. 1990), PIT-tags (Prentice et al. 1990) and colour spots of alcian blue (Hart & Pitcher 1969) and acrylic paint (Lotrich & Meredith 1974).

In February 1990 all eels were treated with mebendazole against the gill parasites, *Pseudodactylogyrus anguillae*. This took place in the rearing systems with recirculation closed (no new water supply) when the eels were exposed for 49 hrs to mebendazole at a concentration of 1 mg/l rearing water as recommended by Buchmann and Bjerregaard (1990).

For every month the following parameters were computed for each tank:

$$\text{Specific growth rate (SGR) in \%/day} = 100 \times \left(\sqrt[d]{\frac{L_1+D_S}{L_0-R_0}} -1\right), \text{ where}$$

L_0 = living weight (g) of eels at preceeding sampling,
L_1 = living weight (g) at present sampling,
R_0 = weight (g) of eels removed at preceeding sampling,
D_S = weight (g) of eels found dead since preceeding sampling,
d = number of days since preceeding sampling.

Total weight (TW) = $L_1 + K_L$, where
K_L (known losses) = cumulative weight (g) of dead and removed eels since the beginning.

Mean feed ratio (MFR) = $(F_S/d)/((L0 + L1)/2)$, where
F_S = dry weight (g) of feed given since preceeding sampling.

Estimated number = L_1/MW, where
MW = mean individual weight estimated from sample.

The different temperature units were completely terminated in 1990 after 92 (May, 26°C), 111 (September, 20°C) and 115 experimental weeks (October 17°C), respectively.

Different tests available in the program package "SPSS/PC+, V2.0" (Norusis 1988) were used in the evaluation of data. Specific growth rates (SGR) at different temperatures were compared with analysis of variance (ONEWAY). This test was always combined with available tests for homogeneity of variances and Scheffe's Multiple Range Test. The procedure CORRELATIONS was performed with SGR and a range of eel population and water quality variables. The variables were earlier exposed to Kolmogorov-Smirnov Goodness of Fit Test in order to test for deviation from normal distribution. When necessary the data were log(10)transformed. Total weight (TW) in May 1990, as well as the final fractions of eels that could be accounted for or that reached at least 30 and 40 cm, was tested for differences between temperatures using Kruskall-Wallis 1-way ANOVA. Chisquare test was used in comparing length frequency distributions in samples from May 1990 with the corresponding data of all individuals in the tanks as expected distributions. A test for differences between estimated and counted numbers was performed with Paired Samples t-test, and analysis of variance (ONEWAY) was used to test whether the ratio between estimated and counted numbers differed between single tanks, temperatures, counting occasions or classified sample sizes (<100, 100-129 and >129 specimens per sample).

RESULTS

Growth at different temperatures

The specific growth rate (SGR) varied between slightly negative values to maximum levels of 1.01 to 1.15%/day in the different tanks (Fig. 1). In general SGR displayed a decreasing trend. The dramatic drop at 20°C in autumn 1988 was probably due to a bacterial disease, which also caused an elevated mortality rate. The simultaneous drop at 17°C might also have been due to the same cause although the only notable observation at that time was a lowered food intake. By spring 1989 the temperatures had been accidently raised twice at night. On the second occasion in May, the eels at 20°C were subjected to an increase of 10° increase, which caused an immediate mortality and possibly suppressed the growth of the survivors. The introduction of feeding apparatus and/or the mebendazole treatment against gill parasites at the beginning of 1990 might explain the increased SGR at 26°C, even though simultaneous treatments in all tanks had no observable effect on SGR at 17 and 20°C.

A comparison of all data, from the beginning to May 1990 when termination of the experiment was begun, showed no significant differences in SGR between temperatures (ONEWAY, $p=0.30$). Some differences were displayed during different periods of the experiment. SGR at 26°C was significantly higher than at 17 and 20°C during 1988 (ONEWAY and SCHEFFE, $p<0.01$) and higher at 20 than at 26°C during both the first ($p<0.01$) and the second half ($p<0.05$) of 1989.

The same data from all nine tanks displayed a positive correlation between SGR and mean feed ratio (MFR), estimated number of eels and pH (Table 2). SGR was negatively correlated with total and living weight, with logtransformed mean weight (MW) and with experimental week number. The last variable had by default a uniform distribution (nine observations per week number) which could not be transformed to

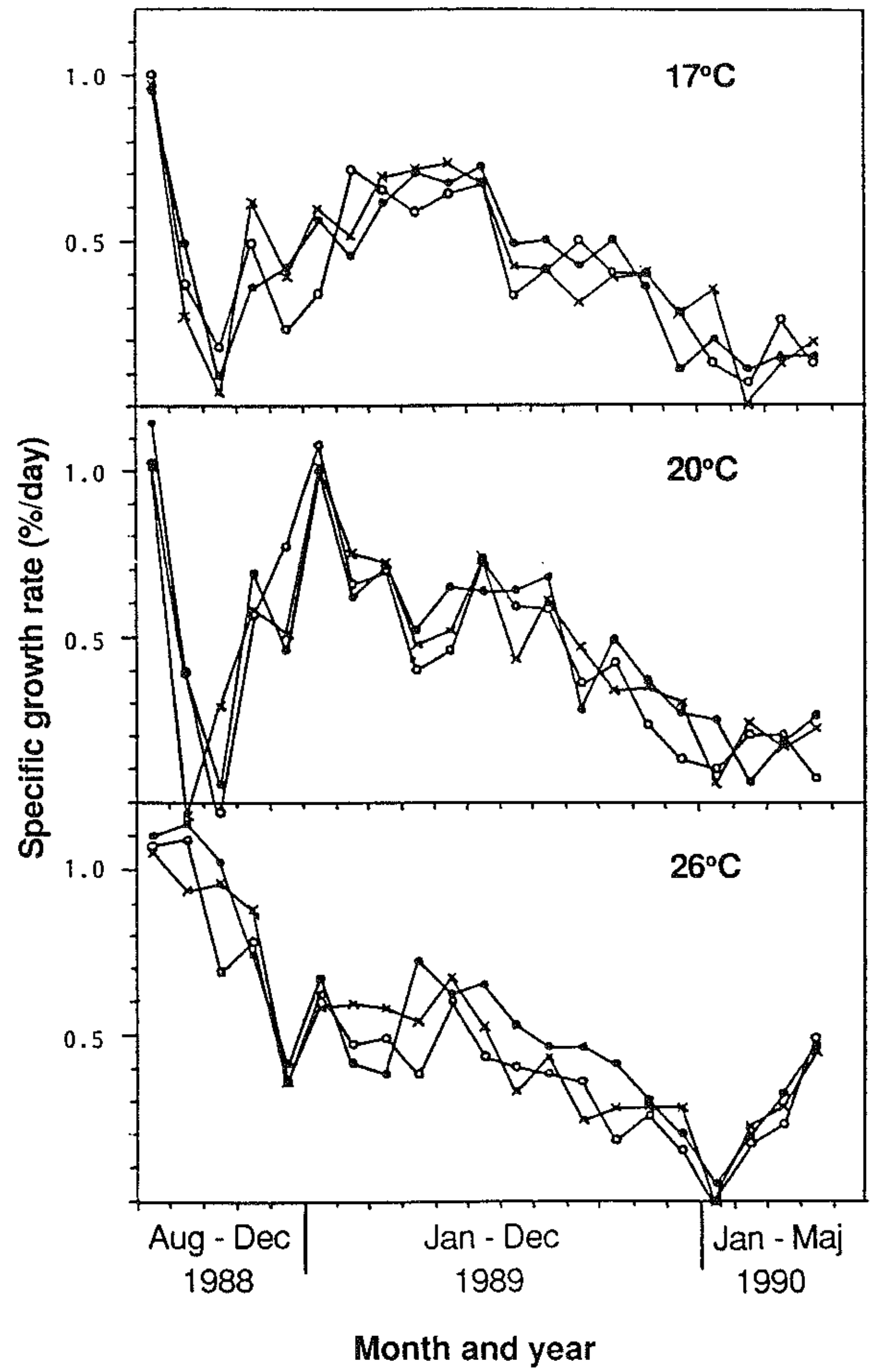

Figure 1: Monthly measurements of specific growth rate. ● tanks 1, 4, and 7; o tanks 2, 5 and 8; x tanks 3, 6 and 9.

normal. No significant correlation was found between SGR and oxygen, ammonium or nitrite concentration. The data set was not suitable for further analysis with stepwise multiple regression since most of the variables correlated with SGR were also intercorrelated with each other.

There was a gradual increase in total weight in every tank, at least until May 1990. The living biomass occasionally showed a temporary decrease due to mortality or to the removal of large individuals (Fig. 2). In May 1990 there was an inexplicable total mortality of eels at 26°C. During the following months the removal of large eels was intensified and the last tanks, at 17°C, were shut down in October 1990. In May 1990 there was a significant difference in total weight (Kruskall-Wallis, $p<0.05$), where the values were highest and lowest in tanks at 26 and 20°C respectively (Fig. 3).

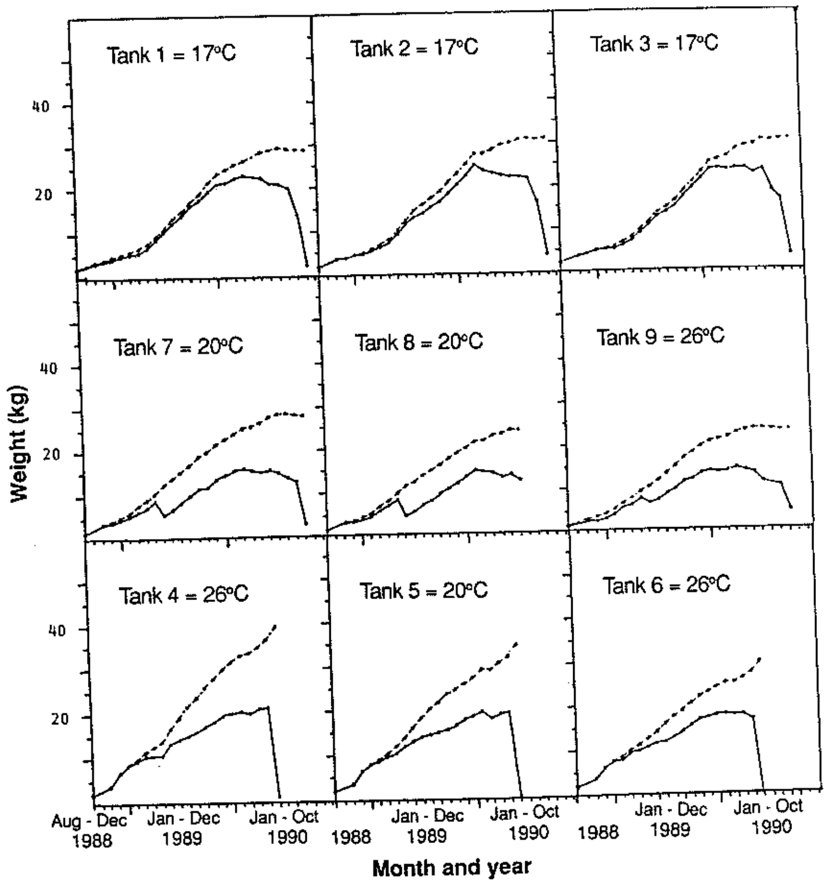

Figure 2: Monthly weights of eels in each rearing tank. Upper (dashed) and lower lines represent total and living weights, respectively.

The proportion of eels that could be accounted for was not significantly different between temperatures (common mean = 64%, Fig. 4a.), nor was the relative number of eels reaching 30cm in length (Fig. 4b.) However, there was a difference in the proportion of eels reaching 40cm (Kruskall-Wallis, $p<0.05$). More

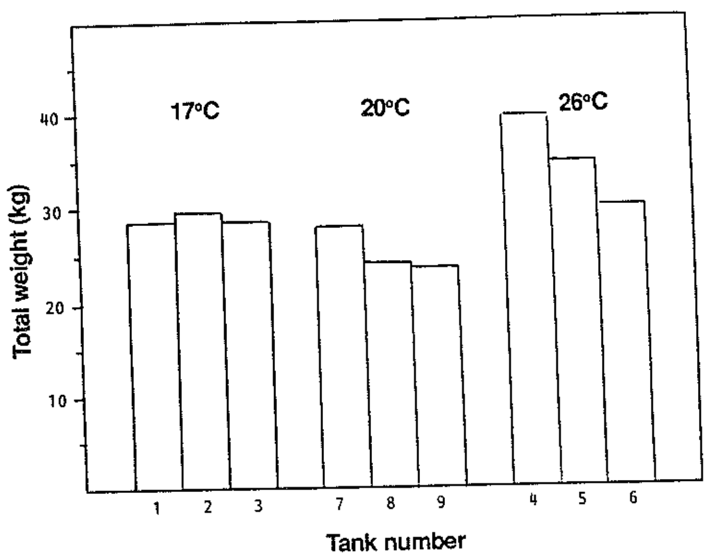

Figure 3: Total weight of eels per tank in May 1990. There was a significant difference between temperatures (Kruskall-Wallis, $p<0.05$).

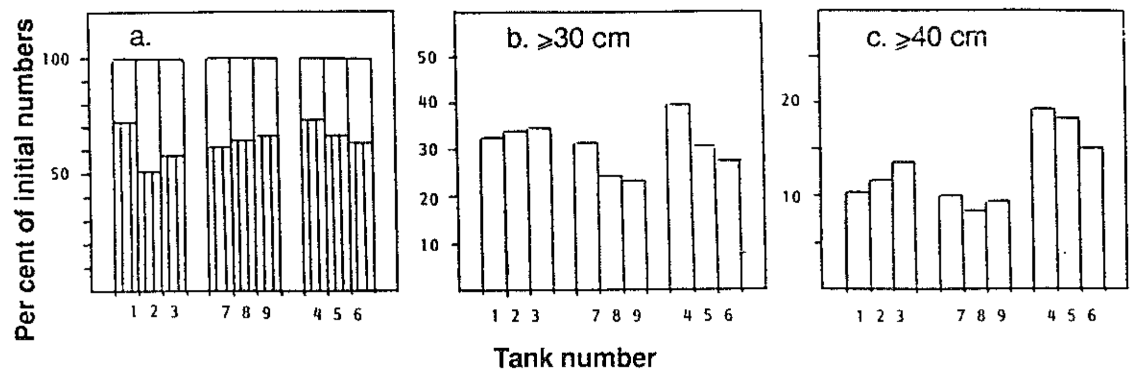

Figure 4: Final relative numbers of eels per tank. a. eels that could be accounted for (striped bars), b. and c. eels that reached at least the specified lengths.

eels reached this length at 26°C than at the lower temperatures (Fig. 4c.), although the time taken to do so was 4-5 months less than the total time of the experiment.

Representativity of length and weight samples

The design of sampling offered two possibilities to check representation of eels of different sizes. Firstly the eels both in samples and in the total remaining populations were measured in May 1990. About a third of the remaining eels were included in samples at 17°C. For each of the three tanks there was a significant difference between observed and expected length frequency distributions (Chisquare, Tank 1: $p<0.001$, Tank 2 and Tank 3: $p< 0.05$). A graphical display of the combined tanks showed that the smallest eels were under-represented in samples (Fig. 5). The same trend was indicated at 20°C (not shown), but the difference was not significant.

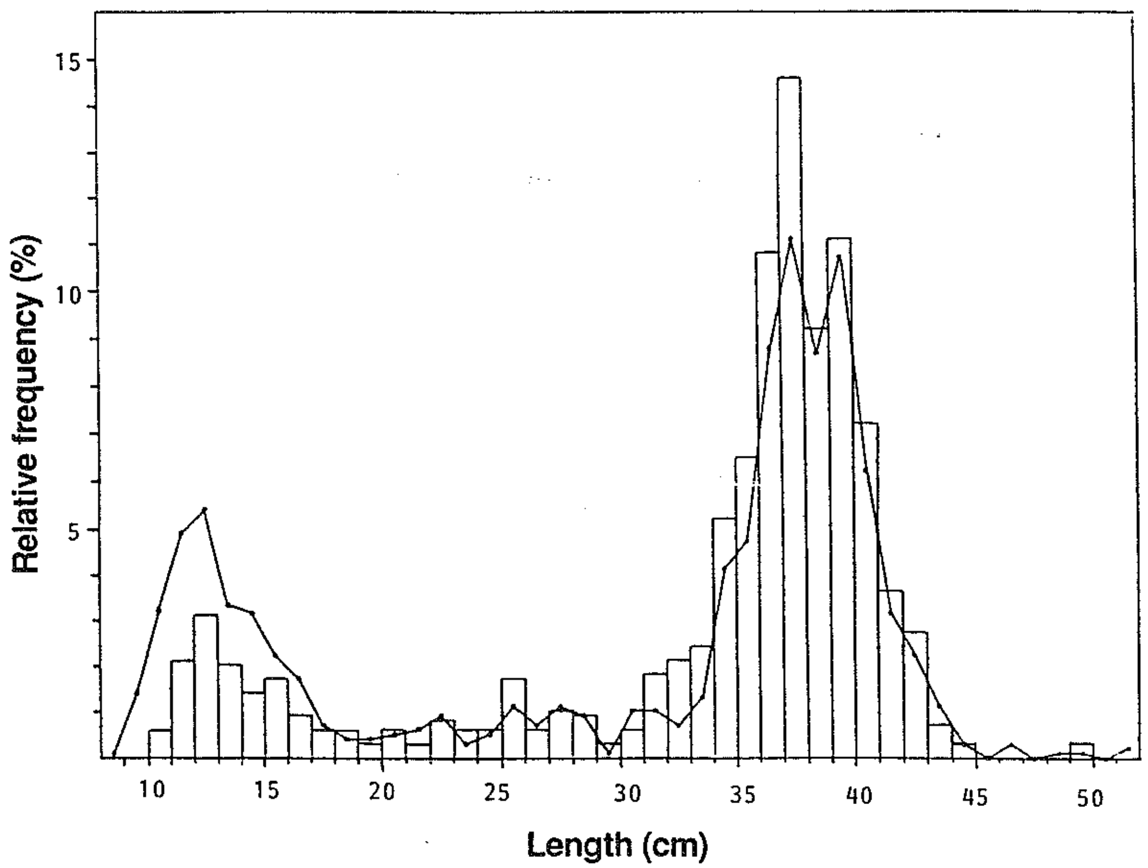

Figure 5: Relative length frequency distributions of combined measurements from 3 tanks at 17°C in May 1990. The line represents the true (expected) distribution of 977 eels, and the bars are estimates from one sample per tank (in total 330 eels).

Secondly, all eels were counted on five occasions. These showed no difference between estimated and counted number of eels for the nine tanks (Paired t-test, $p=0.685$). 29 of 45 observations (64%) fell within 10% deviation (Fig. 6). The estimated mean difference was −3.1 individuals and the standard deviation was 54.5. Unfortunately the ratio between estimated and counted numbers differed between temperatures and between classified sample sizes (ONEWAY, in both cases $p<0.01$), although there was no difference between either single tanks or counting occasions (Table 3).

The number of eels was most often overestimated at 26°C, and the opposite deviation was found at 17°C (Fig. 6). Whenever sample size was lower than 100 individuals, the number of eels was underestimated, which corresponded to an overestimated mean weight.

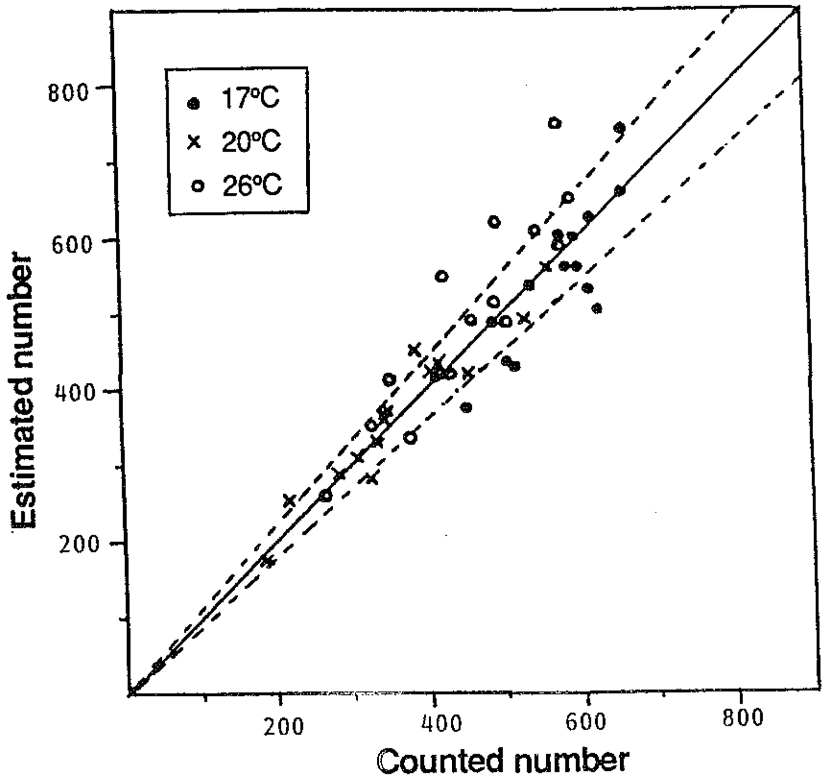

Figure 6: Difference between estimated and counted numbers of eels on five occasions from January 1989 to February 1990 (45 paired observations). Estimates from tanks at different temperatures are marked. The 1:1 line is surrounded by dashed lines for 10% deviations.

Illustrations of growth patterns

The shape of the length frequency distributions changed during the experiment, and the trends were similar at the different temperatures. At the beginning the distributions were slightly positively skewed. As the eels grew and the individual numbers decreased (due to dead, removed or otherwise lost eels), the distributions changed through quite uniform to finally well expressed bimodality (Fig. 7 and 5).

The taggings and markings showed not only a wide variation in growth rate, but they also indicated that individuals must have changed from slow to fast growers (and vice versa) during the experiment. This was illustrated by extracting some typical examples from jaw-tagged and other individually recognised eels (Fig. 8.). The earliest tagged eels were initially fast growers, but their growth soon declined. These eels finally were shown to be males. In the later phase of the experiment more medium sized eels were tagged and recognised. Some of them showed increasing and remarkably high instantaneous growth rates. It is worth noting that if their most exteme growth is simply extrapolated back to earlier dates, it shows that they could in several cases have originated from the lower part of the initial length distribution. They could even have been nongrowing for several months. The late fast growers consisted almost entirely of females. There therefore seems to be a connection between sex and individual growth patterns but the material is not suitable for relevant statistical analysis.

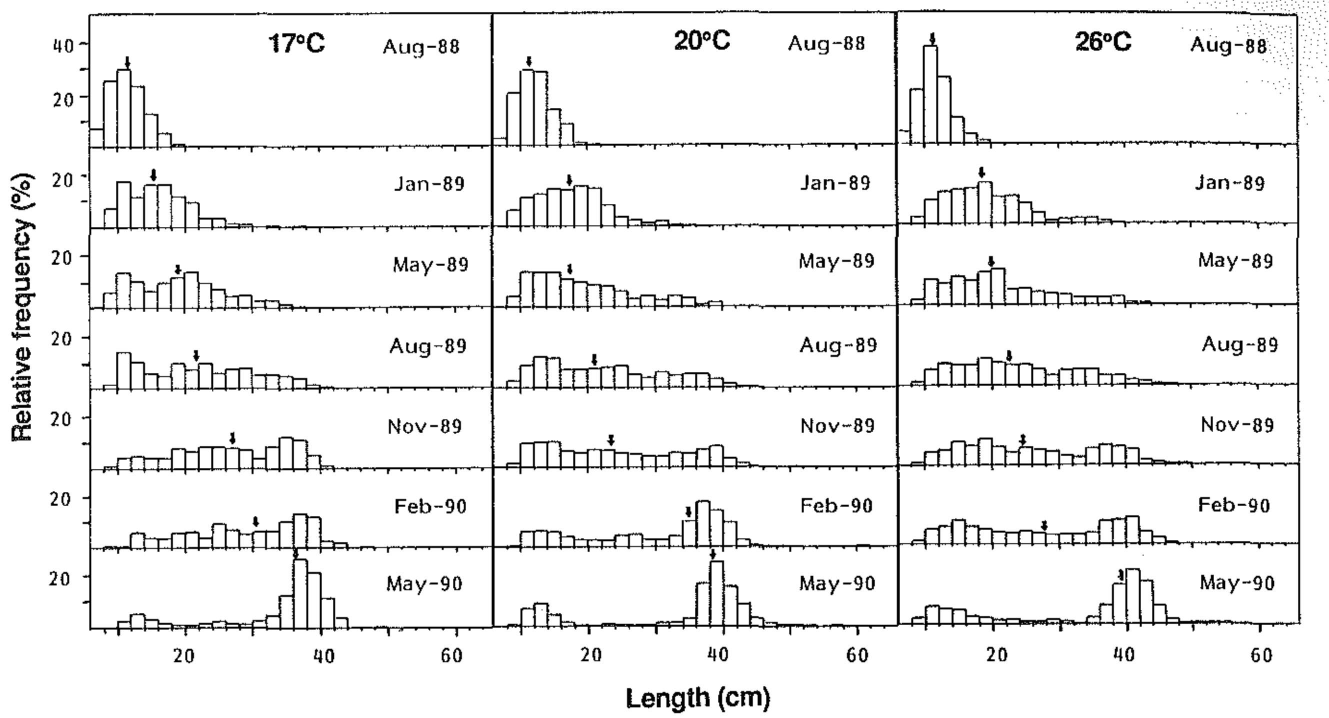

Figure 7: Relative length frequency distributions of eels at the start of the experiment in August 1988 and on six counting occasions. The data are derived from samples in each of three tanks per temperature. Arrows indicate median lengths.

DISCUSSION

Factors with possible impact on growth rate

In this study the specific growth rate (SGR) was estimated with an equation modified from the one used by e.g. Kastelein (1983) and Koops and Kuhlmann (1983). Other authors (e.g. Wickins 1985, Degani et al. 1986, Seymour 1989) used the wider spread formula, for specific or instantaneous growth rate (G), described by Ricker (1979). Some comparisons between the methods gave almost exactly the same results within the observed range of SGR.

During the experimental period of 21 months until May 1990, there was no difference in SGR between the temperatures 17, 20 and 26°C, although the highest temperature was intended to be close to the optimum according to earlier eel growth studies (Kuhlmann 1979, Dosoretz and Degani 1987, Seymour 1989). In general SGR decreased during the experiment.

The mean feed ratio (MFR) varied between 0.4 and 1.8%/day. These values are low compared with others reported estimates, with dry food consumption of up to several %/day (Seymour 1989). SGR was positively correlated with MFR. The distinction between cause and effect is not clear, because the daily ratios were such as to allow for small surplus supplies registered as uneaten food. Before installation of the feeding apparatus, 16 months after the start of the experiment, the eels were fed only twice daily. Seymour (1989) showed that elvers of 1-2g size displayed maximum SGR at about 26°C, when they consumed 3-4% dry feed/body weight and day, supplied at 4-8 meals. The optimum temperature was lower at reduced daily feed intake. At 20-25°C a consumption rate of around 1%/day was required for maintaining the weight.

The number of eels per tank decreased continuously due to mortality, removal of large eels and a non-detectable loss probably due to cannibalism and some escape. The relationship between SGR and estimated number of eels was probably a false correlation. At the start of the experiment the stocking densities of eels of approximately 2g weight, were less than 2kg/m^3. This was easily low enough to allow for differing behavioural activities as discussed by Seymour (1984) and Knights (1987), i.e. that small eels tend to swim around near the surface and larger eels more often rest at the bottom.

A reduction in SGR with increasing biomass is expected if the water quality is simultaneously decreased. There was no correlation between SGR and oxygen, SGR and nitrite or SGR and ammonium concentration. pH decreased during the experiment but the monthly medium value was never below 7.0. This lower level is more favourable than the observed maximum value of 7.7, because the proportion of non-ionized ammonia rapidly increases with pH (Emerson et al. 1975) and a higher pH thereby makes the system more sensitive to accidental high ammonium levels.

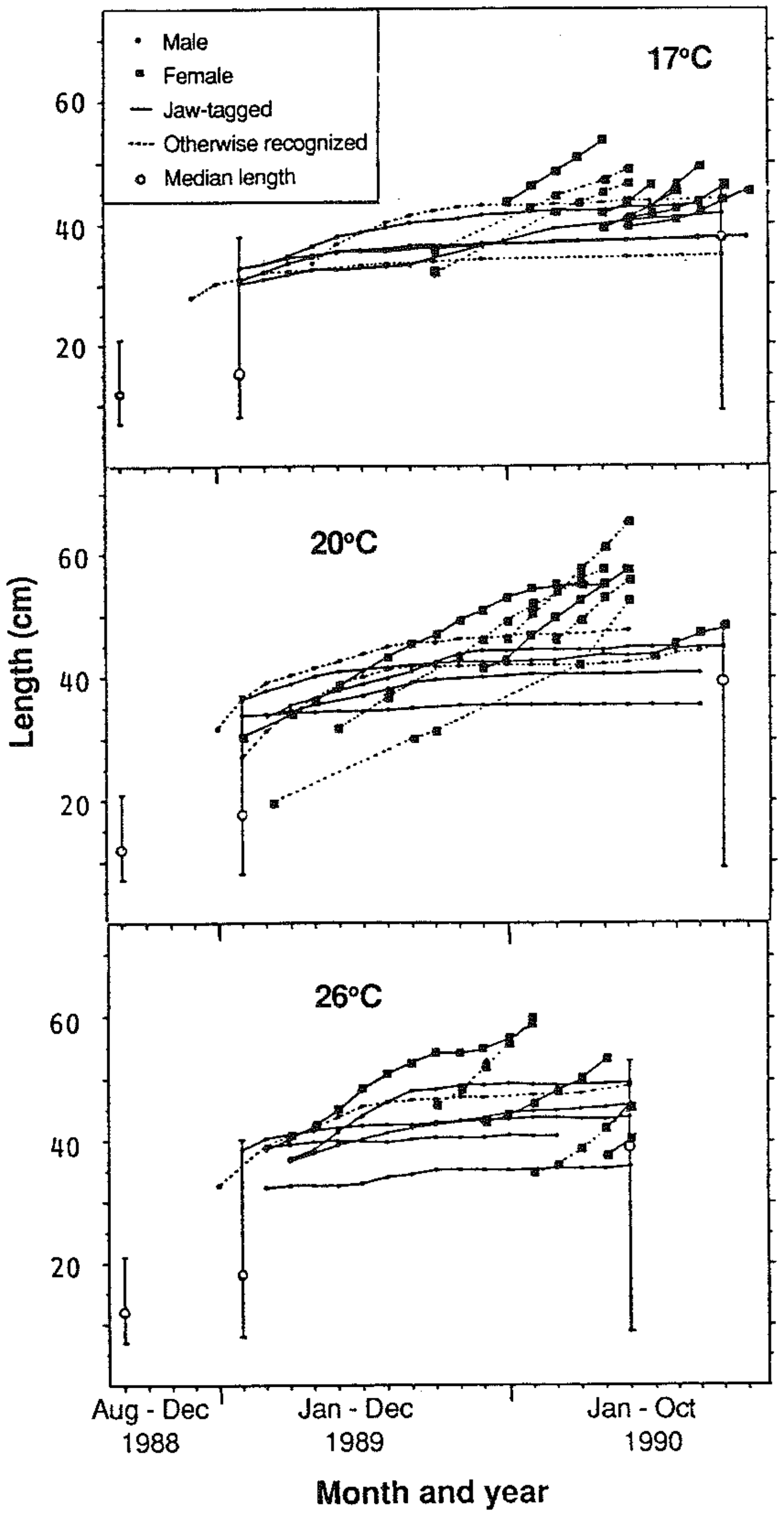

Figure 8: Repeated length measurements of some individually marked eels (subjectively extracted examples) at different temperatures. Median lengths and ranges (vertical lines) are indicated in the beginning in August 1988 and in January 1989. In May 1990 (26°C) and September 1990 (17 and 20°C) all remaining eels were measured.

Reduced SGR with higher mean weight is expected if eels respond as fish in general. Both growth and metabolic rate generally decrease with increasing individual weight. Even though larger fish need lower relative feed rations for maintenance, a relatively steeper decrease in maximum intake ration with size gradually diminishes the scope for growth (Brett 1979). SGR values of more than 2%/day have usually been reported from short term experiments with newly caught eels or elvers (e.g. Penaz et al. 1988). The present study was performed with elvers which had already been cultured for three months before the start of the experiment, and the growth rapidly declines when the eels enter the silver eel stage. In this case more than 90% of the eels which attained at least 25cm in length developed into males and they often became silvery at 100g weight or less (unpubl. data). This might explain the fact that SGR declined to almost zero at mean weights around 100g.

A further factor possibly influenced SGR, namely the infection by gill parasites, *Pseudodactylogyrus anguillae*. After treatment with mebendazole in February 1990 the gills of the eels seemed to be free from these parasites. In summer 1990 the remaining eels at 17 and 20°C were reinfected but to a lesser degree than before the treatment (Malmberg pers. comm.).

Other ways of expressing and comparing growth

Some authors used mean weights (Degani et al. 1985, Degani 1986) or mean lengths (Kuhlmann 1979) for comparing growth rates of eels on different food compositions. This assumes that no individuals are lost during the experiment or that losses are randomly distributed over the entire size interval. Such assumptions are hardly valid in a longterm experiment.

Total weight increment is not sensitive to the loss of some very small eels due to starvation or cannibalism. A notable bias is induced if larger, still growing, specimens are removed from the population. With this bias in mind, total weight in May 1990 significantly differed between temperatures. It was highest at 26 and lowest at 20°C. There was no direct connection with temperatures since the total weight at 17°C fell in between these two values. The tanks at 20°C suffered extremely from unexpected events, such as a bacterial infection in autumn 1988 and a technical failure in May 1989, both of which caused drastically reduced numbers of survivors compared with the other tanks.

It was subjectively concluded during the experiment that growth of early fastgrowers was highest at 26°C. At the termination of the experiment there was a significant difference between temperatures in the proportion of eels that reached and passed the length limit of 40cm. That proportion was higher at 26°C than at lower temperatures. There was no such difference at the 30cm limit. Since there was no difference either in the proportion of eels that could be accounted for, this might indicate that the experiment ran long enough for all eels with sufficient growth capacity in almost ungraded populations to reach 30cm.

It is sometimes interesting to express and compare the growth in different populations after division in length or weight percentiles. For example Seymour (1989) selected the fastest growing eels (25%) in his model for devising optimum feeding regimes. The cumulative known losses of dead specimens might be correctly included in a model describing relative numbers in different size classes, but the size of the eels exposed to cannibalism can only be assumed. As soon as the population is truncated by removal of large eels, it might be preferable to express growth as the time lapse until different percentiles of initial numbers of eels reach a certain size (less than the lower limit for removal). This type of exercise has not yet been presented. In the present study the monthly subsamples were not considered to be representative enough to describe the interesting upper tails in the length frequency distributions of the populations.

Accuracy and precision in sampling for length or weight

Subsampling is often necessary in large populations. Representativity of the sample is a critical point when attained mean weight or length is used as a measurement of growth. This has scarcely been discussed in reports from experimental farming of eels. When sampling young salmon in culture mean weight is usually underestimated (Seeger et al. 1977, Karlsson et al. 1989), but the bias can be minimized by increasing the sample size.

In May 1990, the opposite was found in the present study. Small eels were underrepresented in samples with subsequent overestimation of mean size. This might be connected to the bimodal length distribution, where small eels even in reality constituted a minor ratio with greater need for escaping from larger eels.

When the sample size was less than 100 individuals, the mean weight was always overestimated. This was in spite of the fact that these samples made up 18-51% of the actual populations. This might depend on the extreme size range of the eels. Even within a few months after the start of the experiment the largest eels weighed more than 100 times the weight of the smallest. Single large eels in the samples thus greatly affected the estimated mean weight. The observed difference between temperatures in ratio between estimated and counted numbers, might in some way depend on increased activity of the eels with increasing temperature.

Illustration of growth patterns

When eels grow in culture the skewness and range of the length frequency distribution tend to increase (Kuhlmann 1979, Wickins 1983). It is therefore not easy to summarize the growth of the population using ordinary mean length and standard deviation. Houvenaghel and Huet (1989) described a growth model for eels, up to 45cm in length, where standard deviation increased with time and the relationship between mean and standard deviation remained constant. The model was applied to Kuhlmann's data and it predicted growth as desired. However, it cannot predict the development into bimodal length distributions, which occurred in the present study.

Although silvery males and females often are easily distinguishable becaue of differing size, the appearance of bimodal distributions in cultured eels of equal age has so far not been discussed. By fall a bimodal length frequency distribution was evident for the first year class of largemouth bass, *Micropetrus salmoides*, at West Point Reservoir (Timmons et al. 1980). This was explained by decreasing numbers of adequate prey for the smallest fish during summer. In the present eel study the lower mode corresponded to small eels (about 10-15cm), which were slow growing during the entire experiment. The upper mode was dominated by more or less silvery males whose growth declined at around 34-45cm. During the final year the observed mortality was mainly amongst eels just below medium size (not shown), and dead eels often looked as if they had been bitten. This might indicate that the medium sized eels, i.e. the smallest of the large mode, suffered from the aggressiveness of larger eels. Knights (1987) showed that social interactions such as dominance and avoidance were most marked when the larger eels were about 1.5 times the weight of the smaller.

Wickins (1985) showed that growth variation was higher when newly caught elvers were individually confined than in communally reared groups, while isolation generally depressed growth of fast-growers that had been cultured for 30 days before being isolated. He also studied eels that lost weight during the first 50 days in culture. In isolation some of these individuals grew very fast, up to 6.7%/day, and growth rate was independent of initial size. A study with marked elvers supported the idea that the expression of growth was not necessarily related to previous hierarchical position but may be governed by responses to changed social environment (Wickins 1987). From such results and practical experience it is generally suggested that continuous grading in different size classes stimulates (or prevents depression of) growth rate.

Results from small scale jaw-taggings and other individually recognized eels indicate that some individuals can change from slow to fast growth even in populations with restricted grading. Initially fast growers usually developed into males and their growth soon declined. Fast growers at the later phase of the experiment were shown to be almost entirely females, despite the fact that males constituted more than 90% of the eels that reached at least 25-30cm.

In this kind of longterm experiment, where the purpose is to estimate final sex ratios, it is essential to know the growth patterns of eels that are initially slow growing. it might be fruitful to perform large-scale markings of different size groups at an early stage. If the female ratio increases with smaller initial size at marking, this could suggest that the ratio of potential females is even higher in eels which are lost before attaining the size at which sex could be correctly determined. In an optimal case the sex ratio of these eels could be approximately calculated.

Numbered jaw-tags are suitable for relatively restricted size groups. The smallest size, Nr.1, which was tried in this experiment is appropriate for eels at least between 30-35cm. A smaller tag could certainly be produced, but it would become embedded in jaw tissue as the eel grows. Visible implants have successfully been used in a study of an eel population in a Danish river (Bisgaard and Pedersen 1990). Although 75% of the tags were lost in the present study, the trials were too few to completely reject the method. PIT-tags implanted in the body cavity of juvenile and adult salmonids were well accepted, and the tags did not adversely affect growth or survival (Prentice et al. 1990). The tags are 12mm long and have a diameter of 2.1mm. They could possibly be used for eels down to about 20cm in length.

Group markings using freeze-branding and coloured spots of alcian blue and acrylic paint were also treated on a small scale. Freeze-branding on eels has persisted in natural environments for more than a year (Sorensen et al. 1983, Rossi et al. 1986), but in this warm-water culture the markings became more diffuse with each month and none was recognized more than 6 months after marking. Subcutaneous injection of coloured spots appers to be a better method, and a range of available colours have already been tested on eel (Sadler 1981, Seymour 1984, Knights 1987, Wickins 1987) and on other fish species (Riley 1966, Lotrich & Meredith 1974).

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Table 1. Water quality parameters from August 1988 to May 1990. Range of monthly median values in the central water supply (one sample site) and in eel-rearing tanks (sampling in each of three tanks per temperature).

Sample sites	Oxygen (mg/1)	pH	Conductivity (mS/m)	Nitrite (mg/1)	Ammonium (mg/1)
Central Water Supply	9.2-13.7	7.3-8.1	17-22	<0.0025	<0.5
Tank 1-3 (17°C)	7.8-9.1	7.1-7.7	18-24	0.02-0.5	<0.5-2
Tank 7-9 (20°C)	7.9-8.6	7.1-7.7	18-23	0.04-1.5	<0.5-2
Tank 4-6 (26°C)	6.1-7.5	7.0-7.6	18-23	0.18-1.0	<0.5-2

Table 2. Correlation tests between specific growth rate (SGR) and different variables in the eel populations and water quality. Coefficient of correlation (r), number of paired observations (n), probability value (p) and notes on the underlying distributions of data.

Second variable	r	n	p	Notes
Mean feed ratio (MFR)	0.6348	189	<0.001	1.
Experimental week number	−0.6190	189	<0.001	2.
Logtransformed mean weight	0.5737	189	<0.001	3.
Total weight	−0.5666	189	<0.001	
Living weight	−0.5457	189	<0.001	
Estimated number of eels	0.4875	189	<0.001	
pH	0.4727	153	<0.001	1.
Oxygen concentration	0.1054	189	0.149	
Nitrite cocentration	−0.1109	189	0.138	4.
Ammonium concentration	0.0249	189	0.740	4.

*1. No normal distribution (ND), even after logtransformation,but unimodal around the mean. 2. Uniform distribution (9 observations per week number). 3. ND after logtransformation. 4. No similarity with ND.

Table 3. Tests for difference in ratio between estimated and counted number of eels (Analysis of variance, ONEWAY) with different group variables. In total 45 observations, with mean = 1.018 and standard deviation = 0.116.

Group variable (independent)	Observations per group (n)	F-value	p-value
Tank number (1-9)	5	1.754	0.119
Temperature (17,20 and 26°C)	15	6.086	0.005
Counting occasions (5 times from January 1989 to February 1990)	9	0.343	0.847
Sample size (<100, ≥100-129 and ≥130)	6, 22, 17	5,334	0.009

Lipofuscin used as an age indicator in the European eel *Anguilla anguilla*. Comparison between lipopigment, fluorimetric measurements and otolithometric data

by

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Lipofuscins include several substances, resulting from the peroxidation of cellular lipids from membrane waste (cellular catabolism). Lipofuscins accumulate with time inside tissues, in the form of scattered free granules or concentrated in melanomacrophages centre. Some authors have considered them as possible indicators of the physiological age in some organisms.

The natural autofluorescence of lipofuscins (λex: 360nm — λem: 430nm) enables them to be measured with a spectrofluorimeter on tissue extracts. Dichloromethane extracts of 3 organs (liver, heart, brain) were carried out on glass eels and yellow eels of different ages. The intensity of fluoresence of these extracts (at 430nm) was compared with the absolute age of the eels, determined from otoliths. Age and fluorescence showed a positive correlation, which could confirm the accumulation of lipofuscins with eel growth. However, no reliable standard could be used in determining age by lipofuscin measurements.

The age fluorescence correlation is perhaps low because various types of lipofuscin pigments at different stages of peroxidation correlated either with the normal cellular ageing "age pigment" or with pathological cellular necrosis induced by stress (pollution, starvation, parasitism . . .).

In order to determine the origin of measured fluorescence, the samples were first analyzed for synchronous fluorescence (spectrofluorimeter), and then submitted to high performance liquid chromatography (HPLC). Both these techniques showed that the tissue extracts were, in fact, complex mixtures of many compounds, with spectral characteristics close to those of lipofuscins. Thus, the validity of such fluorimetric measurements should be verified by chemical analysis of the lipopigments.

Preliminary results of otolith shape analysis with eels of known age

by

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It has often been stressed, that most of the common methods for ageing eel show some deficiencies concerning the usual test criteria. A method is presented that is more objective and reliable than direct observation.

The hypothesis that age correlates with shape structure was tested with otoliths from eels of known age. Eels from lake Fardume (Sweden), that were stocked in 1980 and recaptured in subsequent years, were analyzed. Video images of the otoliths were digitized. The optimal sampling frequency for Fourier analysis resulted in normalized shapes of 256 points.

The relationship between age and shape was determined with discriminant analysis of the magnitudes of Fourier descriptors. To check validity, the sample was split at random into equal halves. The first group was used to determine the relevant discriminant functions. They allowed a correct classification of age for 98% of the eels in this group. The discriminant functions were used for cross validation in the second group. With a maximum error of two years 92% in that group were correctly aged.

A clear advantage of this ageing technique over common methods is its reproduceability. Preliminary results of discriminant analysis indicate, that this method can give a significant improvement of validity, presumably in conjunction with direct observation. This method will be refined using data from eel populations of different lakes.

A study of some selectivity factors in eel ladders

by

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Selectivity factors of eel ladders were studied just below an obstacle to the eel's anadromous migration in the Dordogne river. An experimental device caught 6,276 eels over 180.5 hours. The size range varied from 120 to 395mm (mean length 223mm) which was smaller than the size range caught by a neighbouring fish ladder. This result seems to show the selectivity of standard fishways. Various configurations of the experimental device allowed the testing of some selectivity factors. Slope and substrate factors seemed to influence the efficiency. For a given slope, the eel size distribution depended on the substrate, more dense brushes involved a smaller average length of migrants. Selectivity also changed according to gradient. Low gradient (15-30°) should be recommended for such devices and the substrate should be adapted to size distribution of the migrating eels.

Insignificance of tidal currents for silver eel migration as studied by eel trackings and current measurements

by

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ABSTRACT

Three silver eels, tagged with pressure sensing transmitters, were tracked in the North Sea near Helgoland. Swimming depth was almost exclusively between 0m and 17m and, pelagically, mostly between 4m and 14m, the water depth 18-36m. Dives of a few seconds to the bottom occurred, at a maximum once per hour. The speed of the eels over the ground was either faster or slower than the normal swimming speed of the eels during certain tidal periods, according to whether there were favourable or adverse currents. The course of at least one of the eels was to the north, but the tidal currents were mainly east-west. This has been observed also with other eels during earlier investigations. These facts disprove the use of tidal currents as a transporting mechanism for the seaward migration of silver eels. The current data collected during the present investigation are compared with data available from the literature; their applicability is discussed.

INTRODUCTION

During its migration to the spawning area in the Sargasso Sea the Europeal eel *Anguilla anguilla* (L.) has to cross considerable areas with more or less strong tidal currents. The question is therefore whether they could use the seaward flowing ebb tide currents for transportation towards the deep sea. Evidence of the transportation of glass eels in the direction of inland waters was provided by Creutzberg (1959). That the silver eels could reach the deep sea using tidal currents has been shown by computer simulation (Arnold and Cook, 1984). Results of field experiments by the author (Tesch, 1974), with six silver eels in the southeastern North Sea, do not seem to be in agreement with this idea. The eels showed an active compass course movement. These experiments, however provided no depth preferences of the eels. I therefore carried out an additional investigation with eels tagged with pressure-sensing ultrasonic transmitters. I tracked the eels, measuring simultaneously the movement of the currents over parts of the single tracks.

MATERIAL AND METHODS

The eels for the experiment were provided by a commercial fisherman from the Baltic Island of Fehmarn. They were captured 10 days before the experiment using pound nets positioned on the migratory route of silver eels. The lengths of the eels were 96cm (No. I), 90cm (No. II) and 99cm (No. III), and their weights 1.5kg to 2.0kg each. The experiments took place from 2 to 6 November, 1988. The ultrasonic transmitters were from VEMCO, Canada, type V3P1 Hi (Nos. I and II) and V3P3 Hi (No. III), with a pulse length of 25msec and 20msec, an optimum range of 68m and 204m respectively, and a dimension of about 16 × 70mm. While the eel was held in a wooden groove adjusted to body size, the transmitter was sewn onto their backs with nylon thread passed in front front of the dorsal fin. The receiver was a CAI CR 40, the hydrophone a VEMCO V-10 and the depth decoder a VEMCO CI 40. Temperature was measured occasionally by TD sonde and the currents by gelatine pendulum as described by Tesch et al. (1989). Vertical range between current meters was 5m; measurements took place about once per hour, during daylight, more often at high and low water. The tracking vessel was the R.V. "Friedrich Heincke" (length 39m) and determination of horizontal progress and depth of the eel were the same as in earlier experiments (Tesch et al., 1989). A second ship, (the R.V. "Uthörn", length 31m), was used for the hydrographic investigations.

RESULTS AND DISCUSSION

Figure 1 shows the tracks of the three eels released north of Helgoland. No. III was lost after 70 min. No. I was probably damaged during handling and therefore not in a good condition; its mean swimming speed through the water was 0.3kn (knots) — 0.5 knots over the ground. No. II exhibited a swimming speed through the water of 0.8kn (0.9kn over the ground), and therefore had a speed much more in accordance with that of eels tracked previously in the Baltic (0.8-1.4kn over the ground) (Tesch et al., 1989) and in the

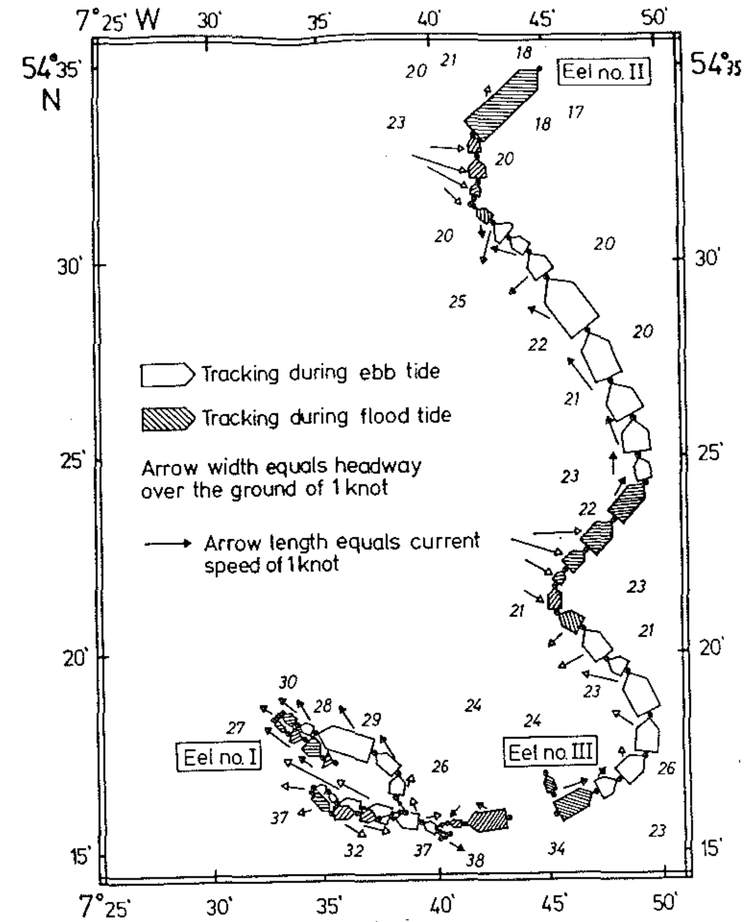

Figure 1. Tracking courses of Eel Nos. I to III. Positions obtained by Decca Navigator are shown by black dots. Black arrow heads indicate currents measured at the respective mean depths of the eel. Open arrow heads currents provided by Mittelstaedt et al. (1983). Numbers along the tracks present water depths.

North Sea (Tesch, 1974). The short tracking of No. III gave a result of 0.4kn through the water and of 0.6kn over the ground.

The current arrows along the tracking courses (Fig. 1) show the current at the preferred swimming depth. It is obvious that the currents have an influence on the course. At flood tide, for example, the currents flow mainly to the east, and the course of the eel is deviated in that direction. At the beginning of the flood tide the current flows in a south easterly direction with a force that equals the speed of the eel swimming against it, that is in the opposite direction. During the beginning of the last flood tide of No. II, therefore, no horizontal progress was evident. During ebb tide the prevailing currents were to the west or to the northwest, this drift assisting the eel swimming in the north westerly direction.

Figure 2 shows the mean hourly depths of the eels, with indications of the tidal phase. At the beginning of the last flood tide during the tracking of No. II, this eel was 5m to 10m deep and the water depth 18m. At no time during the three trackings were the eels at the bottom, except for a few seconds during short dives, (Fig. 3) and with no special depth preferences evident from eels in the Baltic and deepsea areas (Tesch, 1989; Tesch, et al., 1989). The mean depths of No. I during two daylight and two night periods were each 12m. No. II exhibited 9m during the night and 8m during daylight. Number III prefered a mean depth of 11m during daylight. The only pattern which could point to a rhythmic depth preference tendency is the parallelly increasing depth preference of both No. I and II during dawn at the end of the first night (Fig. 2).

The mean direction over the ground of No. II was 358°, and through the water 348°, a negligible difference which points to a minor influence of tides on the migratory route, although the tidal current was mostly from the side. No. I, which drifted considerably because of its slow swimming speed, exhibited a direction over the ground of 288° and a very similar direction of 294° through the water. Six silver eel trackings (Tesch, 1979) resulted in a significant (Rayleigh-test) direction of 340° which is confirmed by the present results. The S-shape of the No. II tracking course can be considered as typical, as this has also been observed in other eels, particularly when they moved in a northern direction (see e.g. eel No. VI in Tesch, 1972).

Table 1 shows temperature profiles in different locations of the tracks. A slight temperature increase from

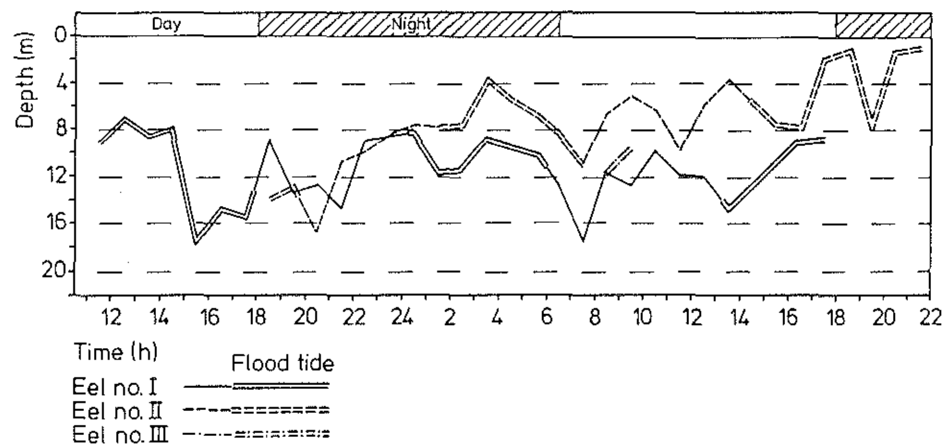

Figure 2. Hourly mean depths of the three silver eels tracked north of Helgoland with indication of the tidal phase. Water depths are shown in Figure 1.

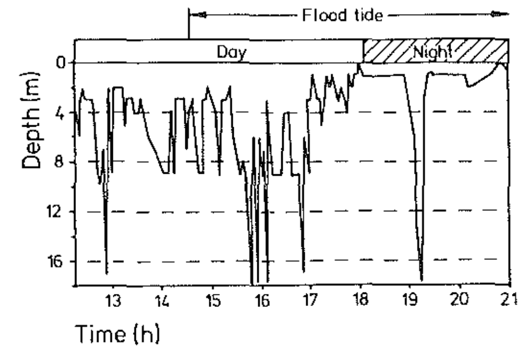

Figure 3. Swimming depths of eel No. II at the last part of its tracking presented in Figure 2. Water depths are shown in Figure 1.

about 24m downwards at most stations is visible. From trackings in the Baltic it is known that the migrating eels avoid deeper water layers probably because the temperature decreases to below 8°C (Tesch et al., 1989). In the North Sea, the vertical temperature relationships were the reverse. However, no preferences for the higher water temperatures in deeper water layers occurred, although the eels could have profited from these layers not only by high temperature, but also because of the lower current speeds during flood tide.

A comparison of the current measurements from the present investigation (A) with those provided by the literature (L) shows a slight difference for the tracking time of No. II (wind: ca Beaufort 2). According to the A-measurements taken over 8 hours, a particle would have drifted 5.8 nautical miles. When L-measurements are considered, its final position would have been 0.8nm farther NE. The wind during tracking of No. I was stronger (mostly NNE, Beaufort 5) and therefore the differences between A and L are higher. 8 hours A-measurements of the drift resulted in 3.0nm of drifting; L-measurements would have given a result of 1.3nm farther NE or in a second case 3.6nm of drifting, 1.7nm farther W. It is therefore doubtful whether a wind strength of Beaufort 5 is low enough for using current data from the literature.

As eel No. I, which was very slow, is useful for testing the applicability of current measurements adapted from the literature, I compared sections of its tracking tested with either A or L for its direction through the water (Table 2). The two sections calculated by A are in accordance with the NW tendency of the whole track and also the test statistic is in accordance with this direction. The section with calculation by L-date shows a completely different result and random-distribution because of the bimodal tendency produced by the tidal currents. The swimming directions over the ground are more in accordance with the NW tendency. Therefore, the use of literature data in this case (low swimming speed, strong wind) cannot be recommended.

It can be concluded that the present investigations, in accordance with earlier results (Tesch, 1974), gave no indication that migratory eels use tidal currents for transportation. (1) The eels are always pelagical, no matter whether during flood or ebb tide. They were therefore also not stationary during flood tide. This was the impression several times during flood tide when no progress was made between stations (Figure 1). This was very likely the misleading impression from the results of Arnold and Cook (1984), considering their Figure 1. From their depth preference curve of one eel it is likely that the eel preferred greater depth during flood tide, but not that it was on the bottom. A tidal dependent depth preference of the eels could also not be observed in migrating eels east of Gibraltar (Tesch, 1989). (2) The speed of the eel during ebb tide was usually higher than the eel's normal speed, which suggests that there was an active movement and not only tidal transportation. This is in agreement with earlier studies (Tesch, 1974). (3) The mean direction of every one of the three eels was different within the northwestern sector and this was also true during previous studies (Tesch, 1974); assuming a transportation of silver eels out of the North Sea by tidal currents (Arnold and Cook, 1984) the eels near Helgoland should all have exhibited the same direction, 290°, which is the prevailing direction of the current during 4 hours of the full ebb tide northwest of Helgoland; but in this case eel No. II moved in 358°.

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Table 1. Temperature profiles during the tracking of eel No. I.

		Stations				
Depth (m)		23	24	25	27	28
0	11,26	11,14	11,16	11,33	11,36	11,39
1	11,26	—	—	—	—	—
2	11,27	11,15	11,16	11,33	11,35	11,35
3	11,26	—	—	—	—	—
4	11,28	11,16	11,16	11,31	11,32	11,33
5	11,30	—	—	—	—	—
6	11,30	—	11,14	11,31	11,31	11,31
7	11,30	—	—	—	—	—
8	11,31	11,18	11,15	11,31	11,31	11,33
9	11,27	—	—	—	—	—
10	11,20	11,18	11,16	11,31	11,32	11,33
12	11,33	11,17	11,16	11,31	11,31	11,33
14	11,52	11,19	11,18	11,31	11,31	11,33
16	11,61	11,19	11,15	11,31	11,31	11,36
18	11,78	11,27	11,28	11,34	11,32	11,38
20	12,02	11,31	11,48	11,60	11,30	11,41
22	12,04	11,31	12,16	—	11,67	11,98
24	12,06	11,31	12,50	12,41	12,36	12,26
26	12,06	11,30	12,53	12,45	12,40	12,32
28	—	11,31	12,53	12,45	12,40	12,35
30	—	11,80	12,53	12,45	12,41	12,36
32	—	12,49	12,53	12,45	—	—
34	—	12,52	12,53	—	—	—
36	—	12,53	12,53	—	—	—

Table 2. Comparison of directions through the water of eel No. I calculated on the basis of actual current measurements (A) and on measurements taken from the literature (L) (Mittelstaedt, 1983).
r = vector length; z = test statistic of the Rayleigh-Test.

Station	Method of calculation	∢	r	z	n	p
1 - 9	A	307°	0,78	5,45	9	0,004
24-32	A	316°	0,45	1,58	9	0,21
1 - 9 and 24-32	A	310°	0,53	5,10	18	0,005
10-23	L	193°	0,14	0,29	14	0,77
10-23	1)	323°	0,20	0,53	14	0,22

1) direction over the ground

Stock density of eel larvae *Anguilla anguilla* (L.) on the European continental slope, based on collections made between 1985 and 1989

by

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ABSTRACT

Twenty to forty-three Isaacs-Kidd Midwater Trawl catches were made in the autumn season of the years 1985 to 1988 and in May 1989. The number of larvae and of metamorphosing stages amounted to 3 to 5 individuals per hour of towing in the Bay of Biscay, and was similar off the west coast of Portugal and Spain. There is probably a small increase of catches compared with those of the period 1981-1984. The 1985 to 1989 catches are still low compared with those of the years 1971 to 1977 (22 larvae per hour of towing). Consistent with the early season the 1989 catches are below average (2 larvae per hour of towing). Northern larvae showed greater lengths than southern larvae which confirms earlier results.

INTRODUCTION

The stock density of eel larvae *Anguilla anguilla* in the Bay of Biscay during the years 1971 to 1977 showed great variation from year to year (Tesch, 1980) but exhibited a comparatively high average. Similar patterns could be observed in the glass eel ascent of the West German River Ems. From 1982 to 1985 a considerable decrease of the eel larval density took place (Tesch et al, 1986) which was accompanied by a corresponding decrease of glass eel catches in several European rivers (Moriarty, 1990) especially in those of the French Atlantic coast (Gerault and Desaunay, 1990). From 1982 to 1984 the eel larval samping was extended to areas of the Iberian west and south coasts (Tesch et al, 1986) but the density of the eel larval stock was not found to be on such a low level as in the Bay of Biscay. From 1986 to 1989 samping in the Bay of Biscay and on the west coast of Portugal and Spain was continued. Of special interest was the western Iberian area because the eel larval catch (Tesch et al, 1986) as well as the glass eel catch (Moriarty, 1990) did not show a remarkable decrease until 1985. This also seems to be true for the Iberian south coast from where, for example in the Guadalquivir until 1984 quite normal catches were reported (C. Fernandez-Delgado, personal communication).

MATERIAL AND METHODS

The sampling took place by R.V. "Friedrich Heincke" (Length 38m) which also performed the greatest part of the earlier collections (Tesch, 1980; Tesch et al. 1986). In accordance to these collections an Isaacs Kidd Midwater Trawl was used, normally with an opening of $6m^2$ or, under bad weather conditions, of $2m^2$. Normal duration of towing, at a speed of 2kn was one hour, occasionally $\frac{1}{2}$ or 2 hours. At each position and during darkness three to five horizontal hauls, generally in a depth of 35 to 100m took place, one position always before midnight, the next position after midnight (from about 0300 hours). Hauls before midnight began at the greatest depth and hauls after midnight at the lowest depth. The mean depths of all hauls varied between years from 63 to 73m considering the phase of the moon (Kracht, 1982) and the normal depth occurrence of the larvae at night (Tesch, 1980; Tesch et al., 1986; Schoth and Tesch, 1983). The depth of the IKMT was controlled by a time-depth recorder but normally estimated by the length of the wire. Leptocephali were sorted on board and, before preservation, measurements of lengths of part of the material took places.

RESULTS AND DISCUSSION

Density

The numbers of eel larvae caught during the different years of the period 1985 to 1989 are presented in Table 1. The catch in the Bay of Biscay ranged from 2,2 to 4.6 larvae per hour of towing and did not show much difference between years. Similarly the catches in the southern areas do not deviate much from year to year nor from the catches in the North. This was considered under the aspect that in earlier years, in the

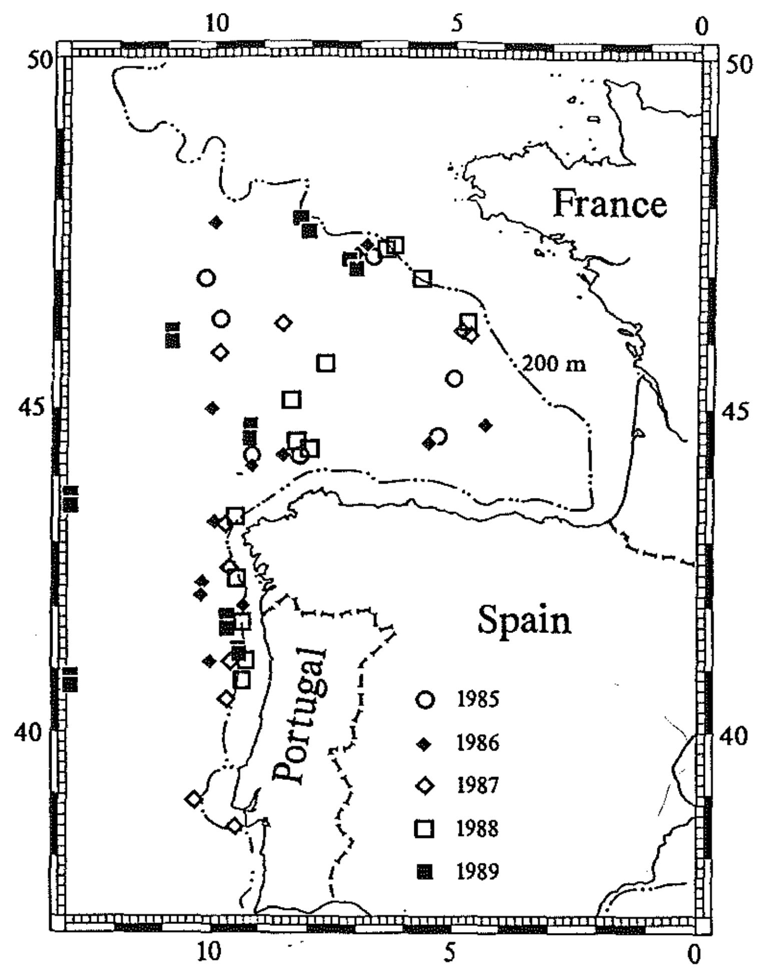

Figure 1. Positions of IKMT hauls 1985 to 1989. Each plotted symbol represents 2 to 4 hauls.

North (Table 2) the level of the catch was much higher although the variation between years in the previous period was greater. Extremely low, during recent years, was the catch in 1989 and, before the period of the present study, in 1981. Catches during both years, in contrast to the other years, took place during the month of May. This is the time before arrival of most of the larvae at the continental slope and therefore the time of the lowest concentration in that area (Schmidt, 1909) and so hardly comparable. Among years of autumn catches, the 1982 catch was lowest with 2 larvae. A statistical comparison (t-test) of this result with the somewhat higher catches during recent years (1987 4.3; 1988 4.6 larvae) displayed a significant difference ($p = 0,03$) between 1982 (24 hauls) and 1988 (27 hauls) but no significant difference on the 5% level between 1982 and 1987 (18 hauls). Similarly, the small difference between 1986 (26 hauls) and 1987 is not significant. Comparisons between other years are useless because the number of comparable hauls is too small. However, a small increase from the lowest value in 1982 to the small peak in 1988 is likely.

In southern areas the density of eel larvae until 1983/84 was higher than in the north (Tesch et al., 1986). This is in agreement with glass eel catches in the West Iberian Rio Minho (Weber, 1986; Moriarty, 1990) which have shown a slight decrease only since 1986, but a stronger decrease during recent years: 1985/86 14t; 1986/87 8t; 1988/89 8t; 1989/90 about 5t (Weber, person. communication). The density of the stock of eel larvae during our samplings since 1986 was low compared with the period 1982-84 and not higher than in the north. A decrease in young eel invasion, although later than in the north, is therefor also confirmed for the west Iberian areas.

Lengths of eel larvae

Results of length measurements in previous years showed that larvae in the south are smaller than in the north (Bay of Biscay) (Kracht, 1982; Tesch, et al., 1986) which has a bearing on the interpretation of the transatlantic migration of the larvae discussed by the author (Tesch, 1983). Length differences between larvae of the area of Gibraltar and the Bay of Biscay were shown to be as high as 10mm. During recent years a comparison of lengths from areas which are closer together shows a corresponding difference (Table 3) which amounts during November catches 1986-1989 to about 3mm. In 1989, when in May only stage I leptocephali were caught, the difference was obviously higher which suggests that in autumn during metamorphosis and in the stage of reducing lengths and partly because of the low number of captured individuals the difference in length is probably less pronounced. Recent and previous results reveal a gradual increase of lengths from south to north which parallels the increasing distance from the spawning grounds to the European coasts of increasing latitude. They provide additional assistance to the hypothesis that an active swimming on a compass course of the larvae during their migration to the European coasts prevails. If there existed only one step of length difference between south and north one could assume that larvae in the south and in the north, are drifted perhaps by two different currents and also could be of genetical difference. But this hypothesis is also contradicted when consulting the length frequency distribution. No two-peak distribution can be detected when the available material is examined under this aspect although the amount of material is rather small for such an examination. The material of 1975 and 1977 (Tesch, 1980) is better. There the length frequency distribution of the illustrated samples is very irregular and more of a one- or multipeak pattern than of a two-peak distribution.

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Table 1. Numbers of eel larvae captured 1985 to 1989 north (N) and south (S) of 43°N and number of hauls (in brackets).

Date and year	Total number of larvae	Number of larvae per hour of towing N	S
11.11. — 14.11.1985	54	2.7(20)	—
31.10. — 8.11.1986	55	3.2(28)	4,5(10)
6.11. — 15.11.1987	111	4.3(19)	1.9(15)
12.11. — 20.11.1988	170	4.6(28)	4.9(15)
25. 5. — 1.6.1989	50	2.2(18)	0.9(12)

Table 2. Density of eel larval occurrence north of 43°N (number of larvae per hour of towing) 1971 to 1981. Season of sampling: M = May, J = June/July, A = August, N = October/November.

1971 J 30	1977 N 21	1983 N 2
1972 J 7	1978 — —	1984 N 3
1973 N 43	1979 M,N 5	1985 N 3
1974 N 6	1980 A 6	1986 N 3
1975 N 42	1981 M 1	1987 N 4
1976 N 6	1982 N 2	1988 N 5
		1989 M 2

Table 3. Mean and standard deviation of total lengths of eel larvae captured north (N) and south (S) of 43°N and comparison between development stages I, II-III and IV-V (after Schmidt, 1909). Number of individuals in brackets.

Year	Area	I	II-III	IV-V
1985	N	72.6 4.1(34)	71.0 3.1(10)	70,1 6.4(10)
	S	—	—	—
1986	N	71.5 4.6(17)	68.4 2.0(15)	69.5 4.4(4)
	S	68.2 2.5(10)	69.6 1.7(5)	66.8 8.0(8)
1987	N	74.7 5.0(12)	69.2 3.5(10)	70.4 5.3(47)
	S	71.5 4.3(22)	62.5 5.0(2)	68.0 — (1)
1988	N	70.3 2.5(10)	69.9 1.7(5)	69.5 3.8(8)
	S	68.2 2.5(10)	69.6 1.7(5)	69.0 8.3(8)
1989	N	73.5 5.0(37)	—	—
	S	66.4 5.0(22)	—	—

Larval growth and drift of the Japanese eel *Anguilla japonica* estimated from leptocephali collection

by

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The larval growth and drift of the Japanese eel were analysed with all of the leptocephali amounting to 109 to date. The relation between TL and collection dates of leptocephali was well expressed with von Bertalanffy and Gompertz equations. The birth date (late May) by the former equation was considered to be more appropriate than that by Gompertz because of the better fit of Bertalanffy equation to the growth of the larvae raised from artifically fertilized eggs. Within the area of leptocephali collection (115°—144°E, 10°-30°N), small sized leptocephali were collected from the eastern and southern half (>130°E, >20°N) in June and July, most of medium size ones from the western and southern half in September, and large size ones exclusively from the western and northern half in November-January. Although there was a bias of collection efforts, this shift of collection areas was attributed to larval drift by the ocean surface currents.

Otolith microstructural growth patterns and daily age of the eel, *Anguilla japonica,* elvers from the estuaries of Taiwan

by

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To increase knowledge of the early life history of the eel, *Anguilla japonica*, the otolith microstructure of elvers collected from five estuaries in the eastern and western coasts of Taiwan during December 1989 through February 1990 was examined by SEM. The elvers arriving at estuaries were ca. 56.0mm TL and showed seasonal decrease in length. The maximum radius of sagittal otolith of elvers ranged from 124.46 μm to 181.82 um with a mean of 143.15±12.72 μm. The microstructure of the otolith from center to edge showed three distinctive different growth phases, the central part is an organic-rich primordium (9.20±2.02 μm in diameter), the 2nd layer is a diffusively calcified core (20.94±1.99 μm), and following the 2nd layer is a zone of daily growth increments. These three layers were probably deposited respectively during embyro, post-hatching yolk-sac and exogenous nutrition periods. The growth rate of otolith of each individual was slightly different but with a common feature, higher (mean 1.0-1.5 μm/day) at 20-30 days post-hatching and c.30 days before arriving at the estuaries, and lower (c. 0.5 μm/d) at 60-90 days old. The mean daily age on arrival at the estuaries on the coast of Taiwan was approximately 170.40±21.02 days. The daily age was not significantly different between estuaries, indicating that the elvers in eastern and western Taiwan were probably recruited from same spawning ground. The growth pattern of the otolith in relation to larval migration was analysed.

The effect of grading on the growth and distribution pattern in young eels *Anguilla anguilla* (L.) reared in recirculating systems

by

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ABSTRACT

Several thousand glass eels were reared indoors for 256 days in glass aquaria (60 l capacity each) in a recirculating system. The first grading took place 70 days after the beginning of the experiment, to three sub-groups: small with individual weights below 0.45g; medium between 0.45 and 1.4g; and large: over 1.4g. Two successive gradings followed, on days 185 and 240, so that on the third grading the subgroups were: small below 1.4g; medium between 1.4g and 7.0g; and large over 7.0g. The remaining fish were raised without grading, serving as controls.

The effect of grading was: sorted fish, small — 19%; medium — 45%; and large — 36%; unsorted control, small — 28%; medium — 58%; and large — 14%. Not only was the proportion of larger fish in the sorted group 2.5 fold higher compared to the unsorted control, but also the average weight of the larger fish sub-group was larger than the unsorted group being respectively, 7.3g and 6.1g.

INTRODUCTION

Glass eel prices are rising steadily. Today in Europe they reach £150 per kg and more, and so far there are no indications of a change in this trend. Considering the facts that survival rates for reared glass eels are, according to the published data, generally around 50%, and moreover, that the proportion of eels which grow very slowly and therefore are of no commercial value is significant, one should look for ways to appreciably improve the culture economy. One way is to increase the proportion of those fish which successfully pass the nursing phase of the culture.

Several authors have noted the advantage of grading eels (Koops and Kuhlmann, 1979; Seymour, 1984; Bejerano, 1985, Bronzi and Zaffignani, 1989) — however, all of them dealt with grading eels of larger size. Gibrat, et al. (1985) graded eels between 0.25g and 1.45g, stating that under their culture conditions size grading was not advantageous, but that it is more profitable due to the removal of the small slow-growing elvers.

Based on our own previous observations on rearing elvers, the present study was undertaken to define the advantages in grading elvers during the first months of culture.

MATERIALS AND METHODS

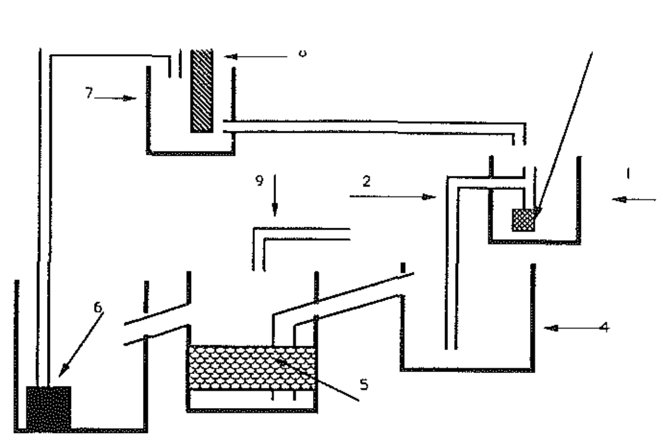
Approximately 18,000 glass eels (5kg) *Anquilla anguilla* L. were reared indoors for 265 days under intensive controlled conditions. The rearing facility consisted of glass aquaria (60 l capacity) combined with a gravel biological filter and sedimentation tanks, forming a partially closed system.

The aquaria were provided with a constant closed system water flow, allowing exchange of the water every 30-40 min. Fresh water was added to the system at a rate which renewed the water in the system within 20-21 hours at the beginning of the experiment, and 7-9 hours at the end. To prevent escape of the eels through water outlets, an electrical device was applied (Appelbaum and Herwitz, 1989).

The following water quality conditions were maintained in the system: temperature 24°-26°C; dissolved oxygen 4.0-6.0ppm; total ammonia 0.25-1.5mg/l. The design of the system used for the experiment is shown in Figure 1.

During the first two days of the experiment, the eels were fed *Tubifex*, then they received minced chicken spleen and pig liver. After 80 days of rearing, eels were fed a paste food consisting of pig liver, fish meal, corn meal, fish oil, vitamins and a binder, mixed in different proportions (Table 1).

After 70 days of rearing, eels in half of the aquaria were sorted by size. Three groups of eels were established and reared separately: small fish with individual weights below 0.45g; medium fish with individual weights between 0.45 and 1.4g; and large fish with individual weights over 1.4g.



1 - aquarium
2 - outlet pipe
3 - electrical device
4- sedimentation tank
5 - biological filter
6 - pump
7 - upper tank
8 - heater
9 - fresh water flow

Figure 1. Design of partially closed system used in the experiment.

The remaining fish in the ungraded control group were reared without changing conditions until the end of the experiment.

Two additional selections were carried out in the medium group only. On day 185 the smallest eels were sorted out and placed in the group of small fish. On day 240, both extremes — largest and smallest eels — were sorted out and placed in their respective groupings.

All selections were carried out using a wooden grading box (own construction), of 40 × 60 × 10cm, across the bottom of which were aluminum bars of 10mm diameter, installed in such a way that the distance between them was adjustable.

After 265 days of rearing, a total count and weighing of both the sorted and unsorted eels was carried out. Three groups of eels were now established: those with body weight less than 2.0g; between 2.0 and 6.0g and larger than 6.0g.

To estimate the difference between distributions, Pearson and Kolmogorov-Smirnov criteria were applied (Lehmann, (1975)).

RESULTS

After 112 days of rearing (about 40 days after the first selection) representative samples of eels from sorted and control groups were weighed individually. The distribution by weight in the sorted and control groups is shown in Figure 2a. The share of slow-growing fish with body weight less than 0.5g in the sorted group was significantly smaller ($p < 0.01$) than in the control groups,while the share of fish with body weight greater than 1.0g was significantly larger ($p < 0.01$) in the sorted groups.

The distribution by weight of the eels in both the sorted and the control groups after 265 days of rearing (and two additional slections) is shown in Figure 2b. Among the sorted fish the division of subgroups was: small — 19%; medium — 45%; large — 36%. Among the unsorted fish, the division was: small — 28%; medium — 58%; and large — 14%. The distinct difference between the sorted and the control groups appeared in both the smallest and largest sizes. For the small size group, compare 28% in the unsorted fish, whereas in the sorted group they constituted only 19%. On the other hand, the share of eels with an individual weight larger than 6.0 in the sorted group is 36%, as against only 14% in the unsorted group, which is approximately 2.5 fold higher. The average weight of the sorted larger fish sub-group was 7.3g, compared to 6.1g in the control group.

In addition, among the unsorted groups there were several large specimens of approximately 50g each which presumably were cannibals. The difference between the two distributions was significant ($p < 0.01$). Figure 2 shows a shift of distribution curve to the right in the sorted groups. The pattern of sorting is shown in Table 2.

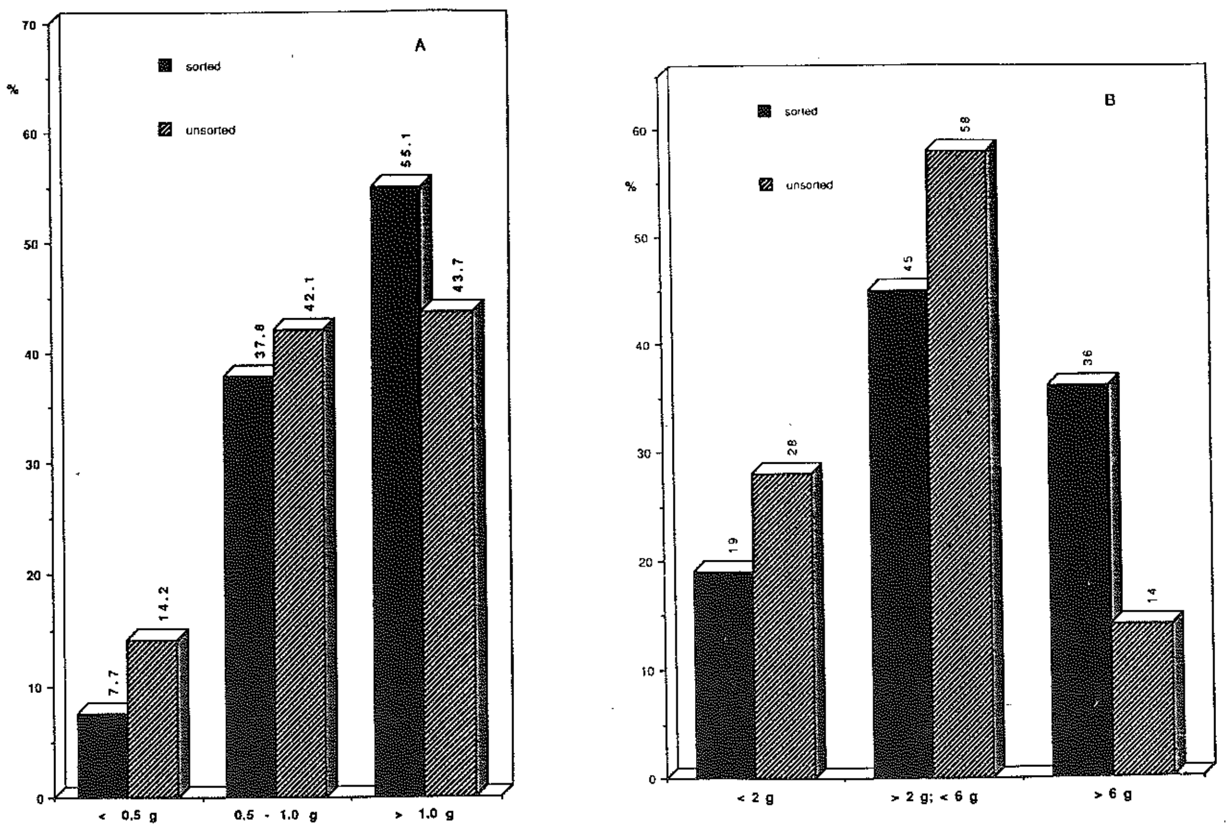


Figure 2. Distribution by weight of eels in sorted and control groups after (A) 112 days and (B) 265 days of rearing.

DISCUSSION

Culturists of glass eels regularly encounter the following general phenomena:

1. Eels which feed well and consequently grow well, and may be characterized as "feeders-growers".
2. Eels which do feed, but grow very slowly, the "feeders-nongrowers", considered by the culturist to be of low commercial value.
3. Eels which do not feed and consequently die, the "nonfeeders-nongrowers".

The proportion of each of these groups out of the total fish in a culture can vary widely due to biotic as well as abiotic conditions. Among the abiotic conditions, feeding and feeding strategy strongly affect the proportions.

The feeding behaviour of eels reared in tanks, at high densities, and fed commercial food, can be characterised in a typical sequence of events: in the early stage of first feeding, for reasons which are not clearly known, a certain proportion of the glass eels are more willing to start feeding and become more easily adapted to industrial feeds, while the rest of the fish of the same group remain distant. Within a period of several days after the bginning of feeding, differences in feeding behaviour become visible. Upon introduction of feed to the tank, the eager specimens, while feeding, congregate around the food, "pushing away" the rest of the fish. As a result, three main groups of eels progressively begin to develop, as mentioned above. The first, showing a gut full of food, are the "feeders-growers". The second group consists of fish showing some food in the gut, the "feeders-nongrowers". And the third group, which hesitate to approach the food and swim around showing no sign of feeding but a migratory-like behaviour, are the "nonfeeders-nongrowers."

The non-uiniform growth among the individuals becomes increasingly evident. Lack of external interference leads to very large specimens and very small specimens in the same group, which is commercially undesirable. Larger and more aggressive specimens not only dominate the feeding area but may also become cannibals, eating smaller specimens, or at least biting them, causing injuries which often result in mortalities. This behaviour is typical of eel culture.

Feeding cultured eels granulated or pelleted feed has become popular during the past 10-15 years. However, it is non-economical to feed a group of non-uniform fish either a single sized pellet or mixed pellets of different sizes. Efficient feeding of fish with granulated food necessitates, therefore, grouping them according to a more or less uniform size. Grading eels seems a practical way to achieve this purpose.

Through many experiments on eels it has become evident that the presence of larger and more aggressive specimens in the group negatively affects the remaining fish. Also the growth rate of the smaller eels is accelerated upon the removal of the largest specimens of the same group. Smaller fish then have easier access to the feeding place and are less stressed by the larger specimens.

Selection of eels has, therefore, the following advantages:

1. The groups are more uniform in size;
2. Uniform sized food can be more efficiently provided;
3. There is less food wasted;
4. There is less aggression and fewer injured fish in the tank.
5. More eels become feeders and grow better.

Selection is not a difficult procedure, and can easily be done using a selection box made of a wooden frame, with adjustable, rust-free bars of 1.0cm diameter, the correct distance apart.

When should the first grading of eels take place? No definite answer can be given as culture conditions differ from one place to another. However, a recommendation can be made: the first grading should take place when at least 40-50% of the eels would not pass through a selection box with a bar distance of 1.5mm. This elver stage can be achieved after a growth period of 2-3 months from the glass eel stage.

Such a grading will lead to two groups: the smaller fish averging 0.40g and the larger fish, averaging 0.70g. The grading process, when done professionally, is quick and harmless to the fish. One person can grade 10,000-20,000 eels a day.

CONCLUSIONS

1. Grading elvers in the first months of culture results in a larger proportion of fish which are economically viable.
2. Grading results in more uniform groups of eels by which a more efficient use of pelleted feeds is accomplished.
3. A proper grading every few weeks is harmless to the eels and obviously does not affect them negatively.
4. More information is needed as to what intervals and into which size classes grading should take place.

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Table 1. The composition of food (in %) given to the eels during the experiment.

Food component	Days of experiment									
	2-4	5-15	16-30	31-45	46-56	57-72	73-82	83-189	190-200	201-265
Tubifex	100									
Chicken spleen		100	50							
Chicken liver			50							
Pig liver				50	100	98	95	93-54.6*	54.6-37*	37
Pig spleen				50						
Fish meal						2	5	5-40*	40-47	47
Corn meal								5	5-9.5*	9.5
Fish oil									6	3
Multi vitamins								0.5	2.7	2.7
Vitamin C								0.1	0.3	0.3
Binder										0.5-1

*During this period the amount of this component was slowly increased or reduced.

Table 2. Pattern of eel selection.

Day of experiment	Boundaries of sub-groups (mg)	Biomass of eels sorted out (%)		
		Small	Middle	Big
70	<450; >1400	6.2	78.4	15.4
185*	<1000<	6.7	—	
240	<1400; >7000	16.4	76.5	7.1

*Sorting out of small eels only.

Experimentally induced sexual maturity in farmed European eel *Anguilla anguilla* (L.)

by

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ABSTRACT

In two experiments (1988, 1989) at Scandinavian Silver Eel, farmed female and male European eels were treated with hormones; females with acetone dried pituitaries, and human chorionic gonadotrophin (HCG), males only with HCG to obtain sexual maturation. The first experiment failed to produce ripe females, probably due to incomplete silvering.

In the second experiment the females were pre-treated for silvering and the gonadal development was close to that obtained in wild eels. Selected eels were treated with 17α,20ß-dihydroxy-4-pregen-3-one (17α,20ß-diOH), which according to Japanese experiments should cause spontanous ovulation. This was not obtained, but a clear effect was noted.

Male eels only had to be treated with HCG to develop into complete maturation. Activity of the spermatozoa was investigated.

INTRODUCTION

Elver ascent on the European coasts has decreased considerably during the last 15 years and in the far East the ascent of elvers of the Japanese eel is not sufficient to fulfil the demands for farming purposes.

Maturation experiments have been carried out with *Anguilla anguilla, Anguilla rostrata* and *Anguilla japonica.* Hatched eggs have been obtained from *A. japonica* e.g. Goos et al., 1988, from *A. anguilla,* Prokhorchik, 1986, while Boëtius & Boëtius, 1980, obtained fertilized eggs from *A. anguilla* and Edel, 1975, obtained mature females of *A. rostrata.* All these experiments were carried out with wild eels. The Japanese have made a few unsuccessful experiments with farmed eels.

We started the experiments with farmed eels because they will be the main source of future breeding purposes, if the trend of decreasing elver ascent and increasing commercial demands continues.

MATERIAL AND METHODS

The experiments were carried out in the Swedish eel farm, Scandinavian Silver Eel, Helsingborg, with eels caught as elvers in the River Severn in England, shipped by air to Sweden and raised on the farm over a period of $1\frac{1}{2}$ to 2 years. The female eels in run (1) weighed from 600 to 1,100 grams and in run (2) from 400 to 800 grams. The males weighed about 140 grams in both runs.

In run (1) all the eels were kept in a through-flow system with brackish water, 7-22‰ and temperatures between 25° and 27°C. In run (2) 6 females were kept in a recirculating system with 34‰ sea water and the rest in the brackish water system at a constant temperature of 24°C. The males, 10 in each run, were kept in an outdoor tank (brackish water) at 22°C.

In run (1) 10 female eels were selected from a batch of growing eels and starved for 8 days before the start of the experiment.

In run (2) 28 female eels were selected from a similar batch in late September and transferred to an outdoor tank (brackish water) exposed to the natural, decreasing day length. The temperature was gradually reduced from 25° to 15°C, kept there till the end of December and slowly raised to 24°C. The eels were transferred to an indoor tank and exposed to roomlight for 10,5 hours/day.

The 18 eels with the most silvery appearance were selected for the experiment and 1 month later 10 silvering male eels were started in the outdoor tank.

At the start of each run the female eels were anaesthetized ($1\frac{1}{2}$% urethan in brackish water) and the length, weight and eye size (horizontal x vertical length mm^2) were measured. The eels were marked individually by fin-cuttings. At death the same parameters were determined plus the weight of the gonads. The gonadosomatic index (GSI) was calculated as the weight of the gonad in per cent of the total body weight.

In run (1) the female eels were treated with HCG and acetone-dried salmon pituitaries (SP) starting November 24, 1988, with 14.3IU HCG and 4.3mg SP/eel. The eels were injected every third week with gradually increasing doses until March 28, 1989 where the dose was 500IU HCG and 35mg SP twice a week. The longest-living eels received 35 injections of which the last 10 only contained SP. A week before

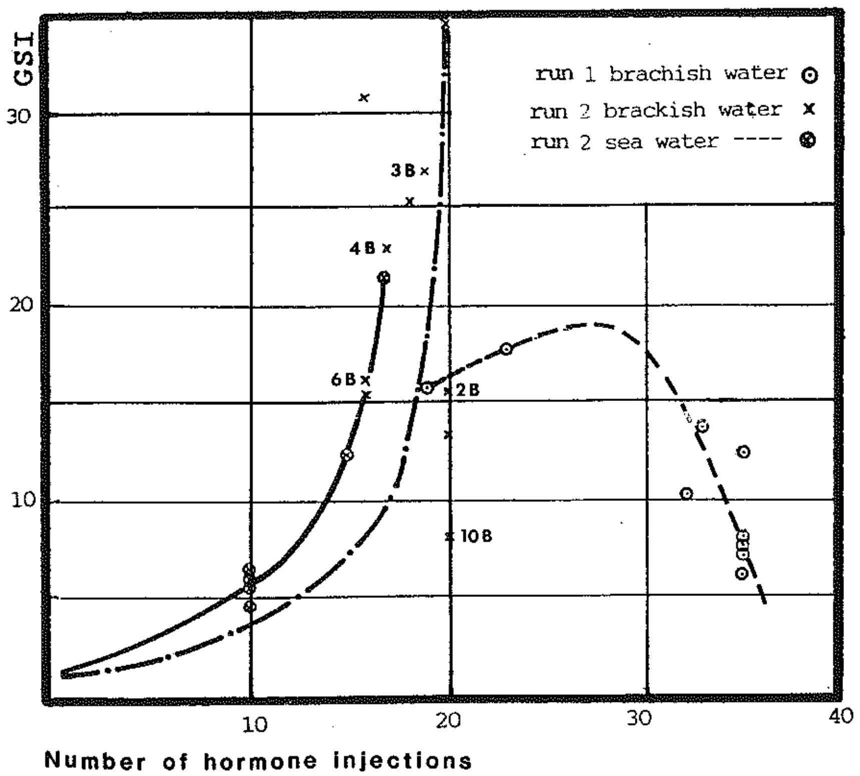

Figure 1. Gonadosomatic index (GSI) of female eels plotted against the number of hormone injections. All curves eye-fitted.

sacrificing, the 5 surviving eels had one injection of luteinizing hormone-releasing hormone (LHRH). In run (2) a maximum of 18 injections of 15mg acetone dried carp pituitaries (CP) and 500IU HCG were given twice a week. Thereafter 1 or 2 injections with only CP and finally one injection of 17α20ß-diOH (1mg/kg eel).

All the male eels were injected 3 times with 500IU HCG/week.

RESULTS

Males

25 days after the start all the males in run (1) yielded milt. During the following period the production of spermatozoa was controlled by alterations in temperature.

All 10 males were sacrificed 5 months after the first injection. 6 of them had still milt with live spermatozoa, 3 were in regression stages and 1 was close to full maturity.

In run (2) 5 males produced milt within a month. All the males were sacrificed after 70 days; 8 of them had live spermatozoa, 1 was in the regressing stage and 1 had not reached maturity.

The activity of the spermatozoa was examined under the microscope and in most cases in 34‰ sea water at 24°C. The activity of the individual spermatozoon only lasted from 10-40 seconds but active spermatozoa could be seen in a sample for 5 minutes. Salinity tests at 10, 14, 24 and 34‰ showed no activity at 10‰ but increasing activity from 14 to 34‰, at a temperature of 24°C. The activity is also temperature dependent and ceased at 10°C. Storage of milt is possible at room temperature for 24 hours and at 5°C for at least 48 hours. The spermatozoa are activated by sea water.

Females

In contrast to the males the females need a continuous hormone treatment until maturation. During this period there is a continuous loss of weight until shortly before ovulation, where a vigorous water uptake takes place resulting in an increase in body weight by 20-40% of the initial weight. The area of the eye is enlarged continuously as long as hormones are induced.

The gonadal development in run (1) is shown in Fig. 1. All the eels had a very low GSI. One week before the eels were sacrificed they were injected with LHRH. No effect could be noted. All the developed eggs were overripe.

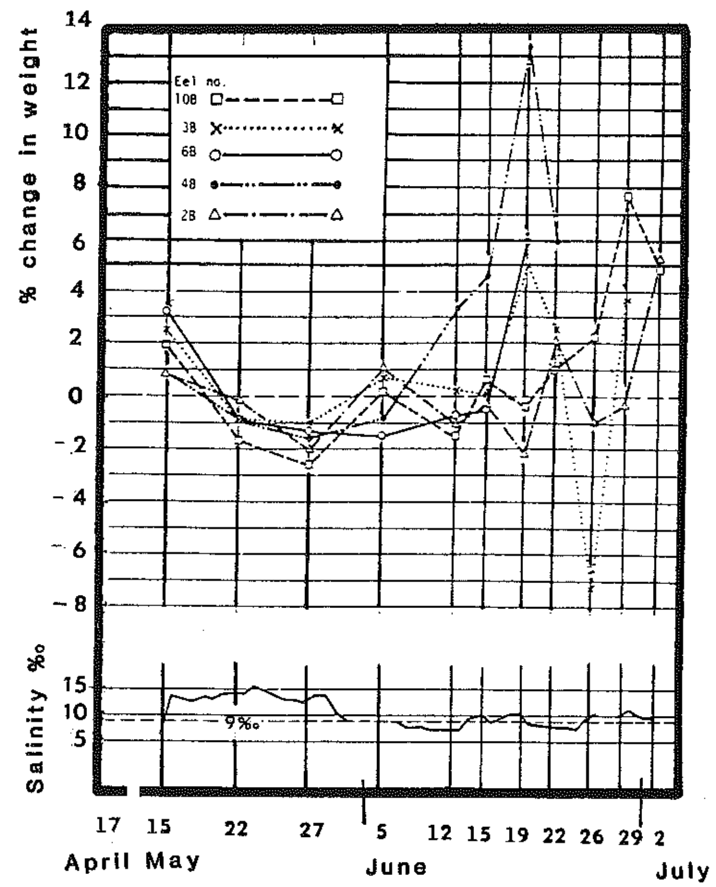

Figure 2. (Top) change in weight on dates of weighing of five selected eels; (Bottom) salinity in brackish water during the experimental period. Run (2), started 17 April 1990.

The eels were weighed initially, after 4 months and at death. After 4 months one eel had gained 6% while the rest had lost 12-20% weight. At death the weight loss was from 20 to 50% of the initial weight. Three of the 9 eels had initial eye areas less than $70mm^2$ which was increased by 100 to 140%, while the rest did not exceed 60% as shown in Fig. 3a.

The GSI values of run (2) are also shown in Fig. 1. Four out of 6 eels in the sea water system died after 9 injections. The 2 remaining eels died after 15 and 17 injections both showing gonads in rapid development. The eels in the brackish water showed that 5 of the 10 eels obtained GSI's above 20 and of these 2 surpassed 30. In run (1) all the GSI's were below 20. Seven of the eels were injected with 17α,20ß-diOH. None of them spawned spontaneously but they all produced a smaller amount of loose eggs.

Four weeks after the first injection the eels were weighed once a week and, close to the expected water uptake, twice a week. The maximum weight exceeded the initial by more than 10% in 4 of the eels. At death 7 eels had a weight that was lower than the initial. Fig. 2 shows the weight changes for 5 of the eels during the weighing period. The numbers of these eels are placed at their final GSI values in Fig. 1.

In Fig. 3b the % changes in eye area are shown. None of the hormone-treated eels had an initial eye area below $70mm^2$ and none of them exceeded a 60% change.

Fertilization attempts

Fertilization attempts were made with both the dry and the wet method with eggs from 3 females in run (1) and 8 females in run (2). Only milt from males with active spermatozoa was used. Artificial sea water 34‰ and temperature about 22°C were used. In no case could cell division or further development be confirmed.

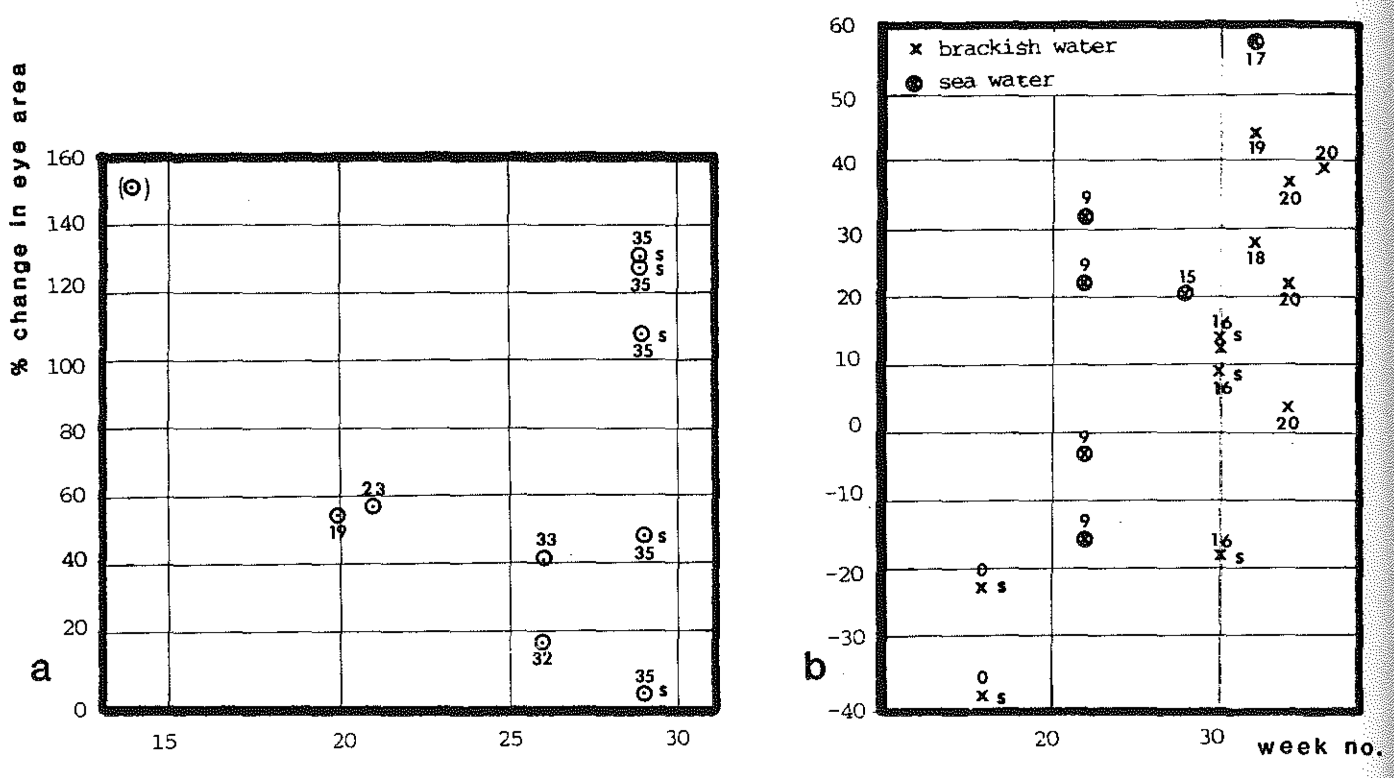

Figure 3. Changes in eye area from start to death. Figures indicate number of hormone injections. S indicates sacrificed eels. A = Run (1) started 24 November 1988, B = Run (2) started 17 April 1990, week no. measured from beginning of year.

DISCUSSION

All the male eels in both runs (1) and (2) were kept in the brackish water through-flow system of the main eel farm during their maturation. They responded to the hormone treatment and temperatures in accordance with prior investigations with wild eels, (Boëtius & Boëtius, 1967). Live spermatozoa could be obtained from individual eels over a period of 2 to 3 months.

All the female eels in run (1) were also kept in the brackish water system during the experimental period. Their gonadal development was slow, probably due to the non or incomplete silvering and periods of too high temperatures ⩾ = 27°C. At this temperature a normal gonadal development can't take place and it might even cause a regression when introduced later in the maturation process.

In run (2) the selection and pre treatment of the female eels resulted in the best development to date of the gonad.

The changes in salinity in the brackish water during run (2) were not very large, Fig. 2, bottom, but as it took place around 9‰. This might have caused difficulties in the osmoregulation. Prior to ovulation there is a considerable water uptake, and consequently a higher weight. In Fig. 2, top, is shown the weight changes in relation to time for 5 eels from run (2). There is no obvious correlation between changes in weight and salinity, but the weight curves are confusing, probably due to the low and changing salinity, 9‰ ± 3‰.

According to Yamauchi, 1989, the final maturation and ovulation was achieved in the Japanese eel by injection of 17α,20ß-diOH when the water uptake had started. We intended to copy this method with the European eel. Seven eels were treated with 17α,20ß-diOH but failed to spawn spontaneously, among other reasons because the beginning of the water uptake could not be defined nevertheless they produced a small amount of loose eggs which could easily be stripped.

According to Boëtius & Boëtius, 1980, wild eels at 30‰ treated in the same way as the eels in run (2) obtained an increase in weight by 30 to 40% of the initial weight after 11-14 injections and at death 88% of the eels had a GSI between 40 and 60, 5% from 20 to 39 and 7% from 10 to 19. In the brackish water eels in run (2) 50% had a GSI between 20 and 40, 40% from 10 to 19 and 10% from 5 to 9. The poorer development in the farmed eels may have two main reasons, that their silvering was not brought to an end and that the low and changing salinity makes it impossible for the eels to control the osmoregulation especially during the water uptake.

ACKNOWLEDGEMENT

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Further experiments on the effects of sex steroids on the gonad sex differentiation of European eel

by

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ABSTRACT

Yellow eels 15-18cm and 22-25cm total length, reared in fresh water at 22-24°C and on commercial eel food, were treated with 17-alfa-methyltestosterone (MT) and with 17-alfa-ethynilestradiol (EE) given with the diet. A very high proportion of the untreated and the MT treated eels developed as males. A significantly high proportion of the EE treated eels, with a high dose (1 mg/kg of food) differentiated as females. In 22-25 cm eels the effect was weaker.

Key words: *Anguilla anguilla*, gonad, sex differentiation, sex steroids

INTRODUCTION

Histological observations on large samples of eel populations have shown that sex differentiation of the gonad is related to the body size rather than to age and ovaries begin to be found in yellow eels from 22-25cm total length (Colombo et al., 1984). It is important to determine at which body size gonad sex differentiation is still sensitive to sex steroids as an indication of the stage of growth at which the gonads are still bipotential.

Oral treatments with 1-alfa-ethynilestradiol of European eel elvers induced a high percentage of ovaries (Colombo and Grandi, 1990).

Further experiments were therefore done on yellow eels of different sizes, and moreover different doses and length of treatments were used. The results on gonad sex differentiation are reported in this note together with some evidence of steroid effects on growth.

MATERIAL AND METHODS

Yellow eels were taken from a stock of elvers caught on the Tyrrhenian coast, brought to the aquaculture plant, reared in running fresh water at 22°-24°C and fed on dry commercial food. They were sampled when they had reached the established length.

Samples of about 150, 15-18cm eels were put in 1m × 1m tanks with 300l of running warmed water and fed with steroid added food. 17-alfa-methyltestosterone (MT) or 17-alfa-ethylnilestradiol (EE), dissolved in ethanol, were sprayed on the dry commercial food which was given daily by an automatic dispenser at a rate of about 5 per cent of fish weight present in each tank. Control samples were fed with food without any addition: in previous experiments the small amount of ethanol used for dissolving the steroids showed no effects.

The treatments are summarized in Table 1.

After hormonal treatment the eels were further reared for some months, fed with normal commercial dry food.

Table 1. Plan of hormone treatments on 15-18cm yellow eels

	Doses of steroids (mg/kg of dry food) MT	EE	Length of treatment (days)
high dose-short duration (HS)	1	10	41
low dose-short duration (LS)	0.1	1	55
high dose-long duration (HL)	1	10	83
low dose-long duration (LL)	0.1	1	87

Subsamples of the largest eels, and subsamples stratified for size, were taken a few months after the beginning of the treatments. After 10-12 months about half of the remaining eels were taken out. They were anaesthetized with chloretone, killed and dissected. The gonads were examined *in toto* by a stereomicroscope and by an optical microscope on histological sections prepared according to the standard techniques.

From the same stock, three samples of about 50 eels of length 22-25cm were put in tanks, as in previous experiments, and fed for 122 days, one with MT (1mg/kg) added food, another with EE (10mg/kg) added food and the third with no addition. When a large proportion of eels were longer than 30cm about half of the fishes were taken out, dissected, and the gonads were examined.

The gonads were classified as:

1) *Undifferentiated* (UN), when they appear *in toto* as a thin thread and in cross section as a gonadal lamella with primordial germ cells isolated or in small clusters:

2) *Syrski organ* (SY), when *in toto* a lobed higher gonadal lamella is seen, and in cross section a larger lamella with rows of germ cells separated by connective tissue;

3) *Ovary* (OV), when *in toto* the gonadal lamella appears as a translucent broad thread, not lobed, and in cross section a larger lamella formed by rows of basophilic oocytes.

In a few cases, gonads classified under stereomicroscope as Syrski organ, actually appeared in the histological sections as small ovaries.

The eels of each experimental group were individually measured and weighed every 2-3 months and survival was also recorded. Except in two cases of failure in water discharge during which the eels escaped, mortality was moderate and similar among the groups. In the longest lasting experiments survivals were around 50 per cent.

RESULTS

Experiments on 15-18cm eels

The frequencies of the 3 kinds of gonads within the experimental groups, are given in Table 2.

The gonad sex frequencies of the MT treated eel groups did not differ statistically from the control, when tested by chi square. Among the EE treated groups those which had the higher dose showed statistically significant larger frequencies of females, and the highest frequency of females was shown by those in the long duration, high dose group.

Table 2. Distributions of gonadal sex in sub-samples of eels longer than 25cm from the experimental groups shown in Table 1 and examined about 1 year after the beginning of the experiments. UN = undifferentiated gonads; SY = Syrski gonad (immature testes); OV = ovaries

Treatments	Control UN	Control SY	Control OV	MT UN	MT SY	MT OV	EE UN	EE SY	EE OV
HL	1	36	1	1	38	0	5	6	30
HS	8	26	1	11	33	1	9	32	11
LL	—	—	—	3	16	0	1	30	1
LS	7	37	2	9	36	0	4	21	3

Moreover, among the eels treated with estradiol at high dose and for long duration, a consistent number (11 out of 25) of females shorter than 25cm, not reported in Table 2, were found.

Experiments on 22-25cm eels

The kinds of gonads recorded in eel subsamples taken six months after the beginning of the treatments are reported in Table 3. Within the EE treated groups some females differentiated.

Effects on growth

Figures 1A and 1B show trends of average values of total length and weight of (on left) eel groups treated at total length of 15-18cm with steroid high doses and for long duration and (on right) eel groups treated (in the same way) at total length of 22-25cm. In the latter group, growth in weight of EE treated eels was significantly impaired.

Table 3. Gonads of eels treated at a length of 22-25cm with high dose of sex steroids for 122 days

Days from the beginning of treatment	Total length	Control UN	Control SY	Control OV	MT UN	MT SY	MT OV	EE UN	EE SY	EE OV
178	25-30	—	—	—	—	7	—	—	14*)	5
	30-35	—	7	—	—	15	—	—	1	—
	35-40	—	6	—	—	—	—	—	—	—
Totals		—	13	—	—	22	—	—	15	5

*) 1 as in control eels, 10 with some oocytes, 3 with many oocytes for gonad cross section.

DISCUSSION AND CONCLUSIONS

In the rearing conditions of the experiments a large percentage (80-90 per cent) of untreated eels developed as males. Sex differentiation appears to be environmentally determined (ESD). Which are the most important environmental factors (temperature, density, nutrition, etc.) is unknown. Some eel farmers obtain a larger proportion of females; it would be interesting to know the devices for obtaining these results in order to have some indications on the mechanisms of eel sex differentiation.

The experiments reported here show that European eels are sensitive to sex steroids from the elver stage up to 22-25cm of total length, a rather long period of life in fresh water in terms of gonad sex differentiation. However the steroid effects are weaker on eels longer than 22cm.

Sex steroids are likely to be involved in the mechanisms of the gonad sex differentiation by affecting some of the early steps of the gonad developmental cascade.

The results of the experiments reported here may be due to a pharmacological effect that can have application in eel culture at least for having all females. Estrogen can be applied on yellow eels not longer than 18-20cm by using a rather high dose for 2-3 months. In longer eels it impairs growth perhaps by a pathological effect similar to that found in salmonids and other teleosts, when given at high doses (Donaldson et al. 1979).

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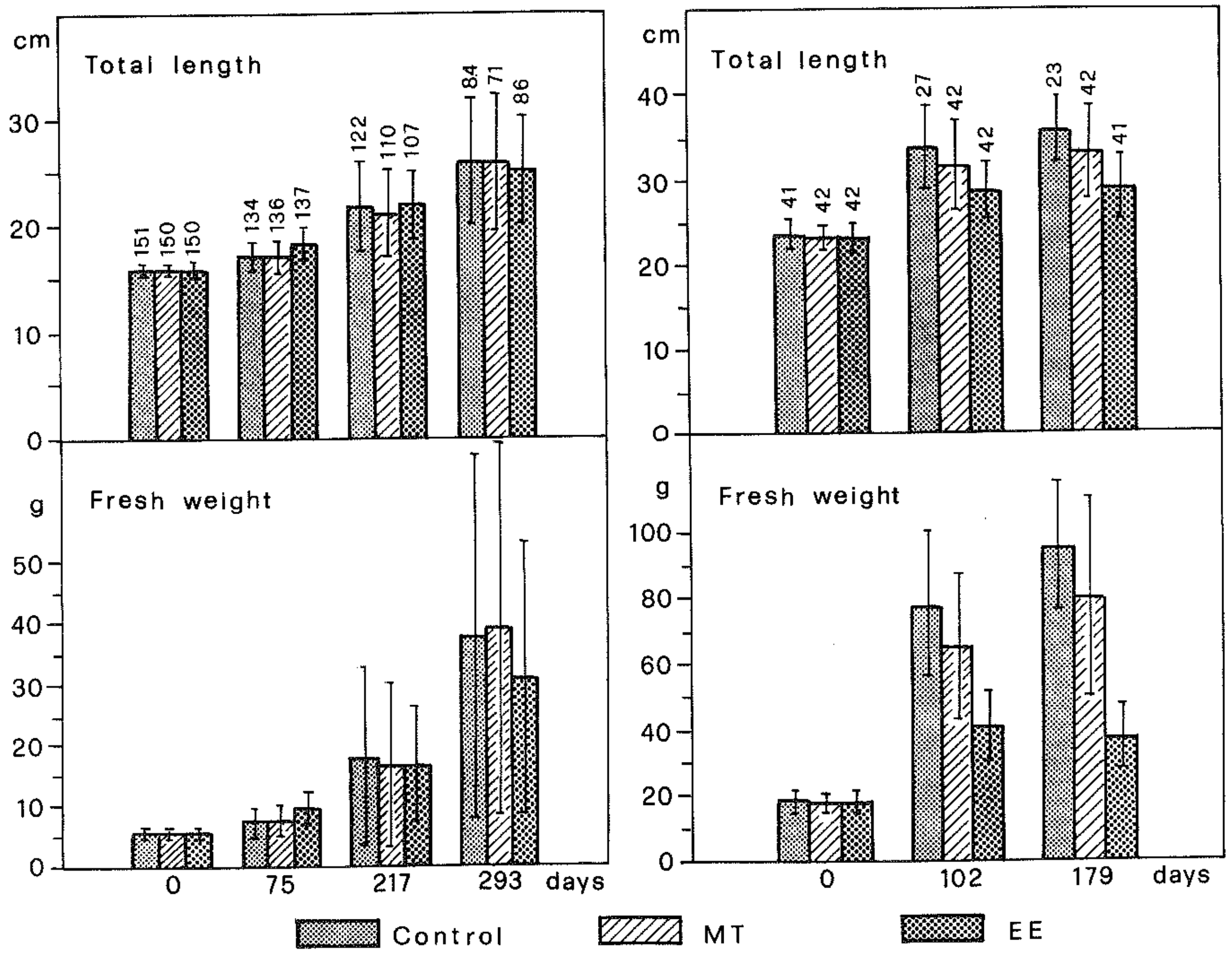

Figure 1. Histograms showing averages and standard deviations of total lengths and fresh weights recorded at different intervals (in days) after the beginning of experiments. Left: Eel groups treated with higher doses and for long duration at total length of 15-18cm. Right: eel groups treated (in the same way) at total length of 22-25cm, the weights of the EE treated eels are significantly less than that of the untreated eels.

Production of eel in recirculation systems in Denmark 1985-1991

by

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ABSTRACT

In 1983 the production of eel in recirculation systems started in Denmark. System design and production technique were based on experience from a research project by the Danish Aquaculture Institute.

In the period 1983 to 1988 approximately 30 private farms of different designs were established. Until 1988 their profitability was limited due to lack of management skills, poor system design, too little standardization in management and system design, loss of production caused by a prasites such as *Ichtyophthirius* and *Pseudodactylogyrus*.

In the period 1988 to 1991 the number of farms increased to approximately 50 and annual production from 235 to 1,000 tons (estimate). During this period the ratio between actual production and estimated production capacity of the existing farms increased from 0.2 to 0.7. The increased productivity is a result of improved management and production equipment.

The profitability of the farms has improved because of a grater extent of co-operation between the farms and between the Danish Eel Farmers Association and The Danish Insitute for Fisheries Technology and Aquaculture.

Scarcity of capital to finance extensions to the plants and a sufficient standing stock of eels, declining catches of glass eels and stagnant prices of farmed eels are the main problems for the trade.

As the price of glass eels is increasing and as up to 95% of the farmed eels become males the farmers take great interest in research aiming at artificial reproduction of eel and techniques to increase the percentage of females in the stock. With the aim to preserve the national stock of eel, Danish waters will be stocked with about 4 million eels size 5-10g in 1991.

INTRODUCTION

Since 1981 research and development of recirculation systems have been carried out at the Danish Aquaculture Institute (DAI), now Danish Institute for Fisheries Technology and Aquaculture, DIFTA, in Hoersholm north of Copenhagen (Jespersen 1989). After 3 years of research on pilot projects in semi-commercial scale the first commercial plants were established in different locations in Denmark in 1983 and 1984.

EARLY DEVELOPMENT

During the years 1983 to 1986, 20 to 30 private plants of various sizes were set up. The smallest plant had a theoretical annual production capacity of 2 tons and the largest one was based on an annual production of 100 tons.

The test results from the pilot plants had been very promising. However, it appeared that there were problems with different factors at the commercial plants.

1) Only a minority of the personnel employed to manage the systems were sufficiently trained to carry out their jobs.
2) Numerous technical design problems occured with the effect that the plants were functioning suboptimally for shorter or longer periods of time.
3) It proved impossible to coordinate and exploit the experience gained from the different plants due to the fact that they varied in size and design and because the farmers were reluctant to pass on information.
4) The farmers encountered problems with diseases, especially the gill parasite *Pseudodactylogyrus*, the Ciliates *Tricodina* and *Ichtyophthirius multifiliis* ("white spot disease").

During the years 1983-1986 no Danish eel breeder succeeded in increasing the profitability of his plant and, despite developments taking place in 1986-1989, that situation remained unchanged.

Problems with productivity in the majority of the plants continued. Figures for the numbers of active plants and total annual production are given in Table 1. In 1988 production actually fell in spite of a small increase in the number of plants.

LATER DEVELOPMENT 1989-1991

The production figures reveal a rather favourable development in production in 1989-1990 and the estimate of 1991. This is not due to the fact that many new plants have been established, but to a significantly increased productivity at the existing plants.

The actual production compared to the production capacity of the plants is shown in Table 2.

The productivity of the existing plants doubled from 1988 to 1990. Still, the estimate for 1991 amounted to only 67% utilization of the capacity of the plants.

There are several reasons for the relatively low productivity:

1) Due to lack of capital many farmers have not been able to purchase enough glass eels and fingerlings and for the newly established farms the market for fingerlings has been too scarce.
2) Of the total number of plants 50% (24 in 1990) have a production capacity of less than 20 tons per year. These plants are run as hobby plants in the sense that the owner typically has full-time employment elsewhere. Therefore, the management of the plants is insufficient.
3) Many farmers have still not gained sufficient experience and capability of running a recirculation system. Therefore, the exploitation of the capacity varies between identical types of plants depending on the capability of the individual farmer.

The progress achieved from 1989 onwards results mainly from two developments:

Exchange of experience and co-operation

The farmers are organized in the Danish Eel Farmers Association.

At the beginning of 1989 a number of farmers decided to hold frequent meetings with the aim of exchanging experience and passing on ideas on methods of improving production.

The farmers in question had extensive experience with the trade. Consequently, it turned out that practically all the farmers within the association increased their production considerably within a few months. Moreover, their initiative inspired others to a more open and cooperative attitude.

The co-operation of the farmers was extended further in 1990 where the Danish Eel Farmers Association joined forces with Danish Institute for Fisheries Technology and Aquaculture, DIFTA, in Hoersholm, Denmark and established a consultancy service.

The consultant was to act as intermediary between the farmers and pass on knowledge and experience. Furthermore, the consultant would be the link between the trade and research institutes in Denmark.

The results of the service so far are that the productivity of the plants has increased as the individual farmer has become more competent as far as managing the plant and the eel is concerned.

Improvement in plant design

As mentioned earlier several technical problems occured in the plants built in the period from 1984 to 1987. However, development in the following years brought about many inventions that were adopted to both existing and new plant concepts.

It seems that several plant designs actually do meet the expectations given in the sales material by the suppliers. A detailed description of improvements which in one case increased the production capacity considerably is given below.

Development of the Plant

The plant was originally built in 1985 and designed for an annual theoretical production capacity of 25 tons. However, it appeared that it was impossible to produce more than 17-20 tons per year, corresponding to a daily feeding rate of 90-110 kilos dry feed.

In 1988 the plant was rebuilt. The rebuilding involved a 30% increase of the total filter area by adding a trickling filter to the original submerged filter. Moreover, the plant had a micro sieve installed on the return water from the fish tanks.

In 1989 the plant was further improved. A UV-sterilization unit disinfecting approx. 10% of the total water volume per hour was installed. These alterations combined with greater experience of the managing staff brought the annual production capacity up to 40 tons corresponding to a daily feeding rate of approximately 200kg dry feed. The increased production was brought about without changing the waterflow or the number of production tanks during the period in question.

Short Description of the Plant

A schematic diagram is given in Figure 1.

The plant is designed as a recirculation production system with a central biological water treatment system. Purification of the process water is done partly mechanically by a micro sieve and partly by a biological filter, consisting of a submerged upflow filter followed by a trickling filter. Disinfection of a partial flow takes place in connection with the biological filter by means of UV-lighting.

After the biological filter pure oxygen is added to the water through an oxygen cone to ensure a satisfactory oxygen level at all times in the fish tanks. An electronic measuring device controls the content of oxygen in the water using an automatic mangetic valve. The operations of the plant are constantly monitored by an alarm system connected to the telephone network.

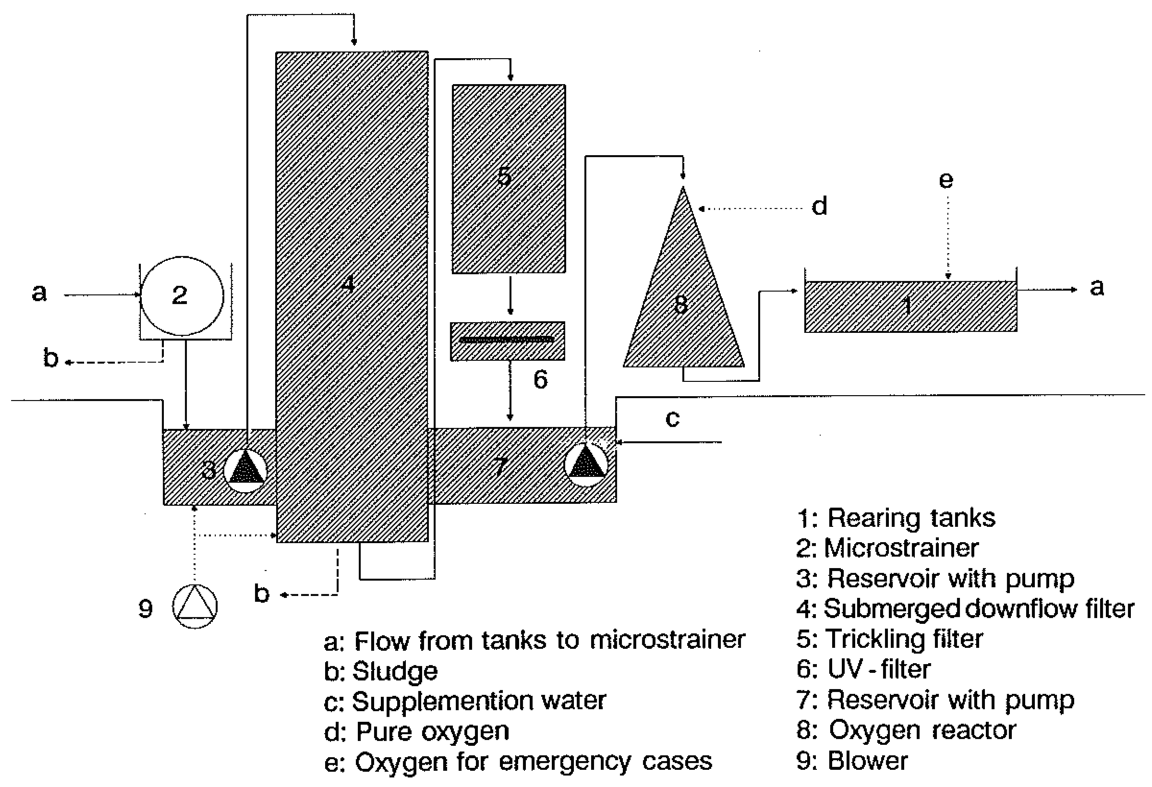

Figure 1. Schematic diagram of module.

Dimensions

The plant is built up of modules each with a total annual production of 50 tons.

The dimensions of the plant are based on the following tested assumptions:

Annual production	50 tons
Average daily growth rate	0.7%
Average feed conversion	1.6
Average standing stock	20.000 kg
Density of stock	55 kg/m^2
Average daily feeding level	225kg
Water temperature	25°C
Daily water consumption	30m^3
Power consumption	35KW/h
Recirculation flow	500m^3/h
Total water volume	450m^3
Retention time in fish tanks	30 minutes

Economics of two Plants of Different Sizes

The budgets tabulated below are based on *realistic* figures of the type of modules previously described. Two plants of different sizes are compared in Table 3. Costs include plant for fingerlings but exclude cost of buildings.

As illustrated in Table 3 there are several obvious advantages of eel farming in large-scale operatoins. On the 200 ton plant 15% is saved on the variable expenses equivalent to 600,000 DKK. As far as fixed costs are concerned (salaries only) savings on the 200 ton plant amount to 60% or 600,000 DKK. Savings on construction costs are 2 million DKK leading to a reduction of interest of 240,000 DKK/year. The end result is that total annual savings of large-scale operations amount to approximately 1.45 million DKK.

This combined with the relatively lower construction costs for the 200 ton plant causes the period of depreciation almost to be halved from 6.5 years to 3.6 years.

Production results

The possibility of realizing the budgets given in Table 3 is inseparably bound up with the breeder's ability to run the plants in question.

This demands experienced staff. Therefore it is recommended that the bigger eel plants for the first couple of years are managed by experienced staff who take on the task of teaching other personnel the skills of eel breeding and convey their knowledge of biological filters.

The production results of Danish eel farmers varies a great deal from plant to plant as far as feed conversion rates and specific growth rates are concerned. Obviously this is subject to the varying experience of the individual farmer as well as the varying designs of the plants.

The results shown below have been achieved at the plant described earlier where the manager in charge of the plant has 5-6 years experience.

Size of fish (g)	*Feed conversion rates*	*Growth rates % per day*
0.3 — 10	1.5	1.3
10 — 25	1.3	1.5
25 — 50	1.4	1.5
50 — 100	1.6	1.0
100 — 170	1.8	0.4

The result is an average growth rate for the total standing stock of approximately 1% per day which is considerably higher than the design criteria of 0.7% per day. The feed conversion rate is equivalent to the one quoted of 1.6.

DISCUSSION

From the foregoing it can be concluded that recirculation eel farms capable of producing market-size eel for consumption with a good profit do exist in Denmark.

The calculated sales price of 55 DKK/kg in the budgets above are equivalent to the actual price (as of mid-June 1991) for farmed eel size 100-200g.

100 — 200g: 57.50 DKK/kg
200 — 300g: 64.75 DKK/kg
300 — 600g: 75.00 DKK/kg

The prices quoted are ex-plant (Danish Eel Farmers Association, 1991). The prices in the first half-year of 1991 have shown a downward tendency and it is assumed that the average prices of 1991 will be lower than was the case in 1990 (DIFTA, 1991). However, the price of farmed eel in Europe is subject to numerous factors and therefore the matter will not be given further attention here.

Danish eel farmers produce primarily small eel for the Dutch market, probably because of the uneven distribution of males and females in the standing stocks. It is assumed that 90-95% of the total number of eel in all of the Danish plants become males and consequently reach a maximum weight of 100-180g. This subject calls for further research aimed at finding ways of achieving a greater percentage of females. If attempts to produce more females in recirculation systems prove successful the average weight of the produced eel will be increased and the trade could become a prosperous business.

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Note:
Rates of exchange as of June 20 1991:
100 German marks= 385 DKK
100 UK pounds = 1,130 DKK

Table 1. Development in the annual production of Danish eel farms 1984-1991 (Danish Eel Farmers Association, 1991).

Production Year	No. of active plants	Annual production (tons)
1984	approx. 5	approx. 18
1985	approx. 15	approx. 40
1984	30	200
1987	30	240
1988	32	235
1989	40	500
1990	47	706
1991	50	1,000

Table 2. Development of productivity in recent years (Danish Eel Farmers Association 1991).

Year	Theoretical capacity (tons)	Actual production (tons)	Utilization (%)
1988	1,000	235	23.5
1988	1,200	500	41.6
1990	1,400	706	50.4
1991(est.)	1,500	1,000	66.7

Table 3. Budgets for plants of 50 ton and 200 ton capacity. Costs in DKK 1,000 (Billund Aquaculture Services 1991).

	50 tons	200 tons
Cost of construction including erection	3,000	10,000
Establishment of "Standing Stock"	1,400	5,000
Total investment	4,400	15,200
Operation budget for a normal year after the establishment of the "standing stock":		
Income	50 tons	200 tons
Sales of eel for consumption at DKK 55 per kilo	2,750	11,000
Expenses (variable costs)	50 tons	200 tons
Feed	520	1,920
Oxygen	160	400
Electricity	116	464
Heating	38	75
Purchase of fingerlings	225	900
Medicine, chalk etc.	80	200
Total variable costs	1,139	3,959
Gross profit	1,611	7,041
Expenses (fixed costs)		
Salaries (2 empl. at 50 t. 4 empl. at 200 t.)	400	1,000
Result before interest and depreciation	1,211	6,041
Interest: 12% of investment	528	1,824
Result before depreciation	683	4,217
Depreciation period	6, 5 years	3, 6 years

Recent developments in eel farming in Italy

by

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ABSTRACT

In 1989 the production of eel in Italy totalled 16,600 tons. Intensive and extensive eel farming produced 4,500 tons and the capture fishery 12,100 tons. Imports amounted to 5,000 tons and 2,400 tons were exported. The total internal market totalled 19,200 tons, considering the difference import – export on the top of total production. Eel farms are mainly located in Northern Italy, because of historical traditions, but recently Southern Italy, too, has become of great interest due to more suitable water temperatures.

Eel prices vary according to the month in which they are sold: higher prices during Easter-time, August and December; the highest prices are observed at Christmas-time.

In spite of the fact that the market offers interesting opportunities to increase the production, bottlenecks still exist, the most important being the availability of acclimated glass eel and young yellow eels for ongrowing. In order to solve this problem, operators should be encouraged to develop the industry of glass eel acclimation and first feeding.

INTRODUCTION

Eel farming has been carried out in Italy for many centuries, since the Middle Ages. Fish traps were built along rivers and channels flowing into the sea. With the purpose of catching the eel during their descent to the sea, coastal lagoons were divided into many stretches of water by fencing them with reeds and building earth banks, thus making it possible to recapture the eel and other euryhaline species (Cognetti and De Angelis, 1980; Ardizzone et al., 1988). Over the centuries, eel farming has always been an important economic activity and, at the present time, Italy is the most important eel producing country in Europe (Cataudella, 1989) and on the world scale, second only to Japan. Information on the state of eel farming in Italy has been provided by Saroglia (1985) and Panella et al. (1980).

However, eel farming in the lagoons, as well as in extensive "vallicoltura" suddenly broke-down between the 1960s and the 1970s, because of parasitic diseases, such as Argulosi, which could not be treated in large fishponds, as the "valli" are (Ghittino, 1983).

Eel Farms

In Italy, eel farming is carried out in about 180 installations, mainly concentrated in the north. A limited number of facilities are in central and southern Italy and, for the most part, have been built recently.

They are mainly specialized eel farms consisting of a group of either concrete or earth basins waterproofed with PVC, where eels are intensively farmed until the market size is reached, either "buratelli" (180-250g) or "capitoni" (500-800g) as average weight. Apart from these facilities, there are the extensive eel farms located in "valli", lagoons and ponds behind dunes, with a total surface equal to 63,000 hectares (ISMEA 1988). The latter are not specialized facilities, but fish farms designed to rear various euryhaline species at the same time in polyculture. Extensive fish farming facilities are mainly concentrated in the northeast of Italy, even though the extent of the lagoons from central and southern Italy and Sardinia is considerable.

Production of the intensive fish farming sector, after a quick growth in the 1970s (Iandoli and Ingle, 1990; Panella and Della Seta, 1987), has reached a constant output of about 2,500 tons, because of the limited glass eel and young yellow eel availability (Ingle et al., 1988; Gandolfi, 1980; Gandolfi et al., 1981). Pathological aspects too, have contributed to limiting the production, coinciding with the parasite *Anguillicola sp.* which first appeared in Italy in the middle of the 1980's (Di Cave, 1986; Sarti, 1986), even if the effects actually due to *Anguillicola* are still controversial among leterature.

The districts which produce the highest outputs in the intensive eel-farming sector are mainly Lombardia (800 tons), Puglia (500 tons) and Veneto (300 tons) (Figure 1); important outputs come from Lazio and Toscana, too. In the extensive eel farming sector, the leading district is Veneto, with an output reaching two thirds of the total extensive production; lower outputs are obtained also in Emilia Romagna, Puglia and Friuli.

The total output in eel from aquaculture in Italy is estimated to have reached 4,500 tons in 1989. On the top of this, 12,100 tons represent the output from capture in inland water plus coastal water and brackish water lagoons, to make a total of 16,600 tons.

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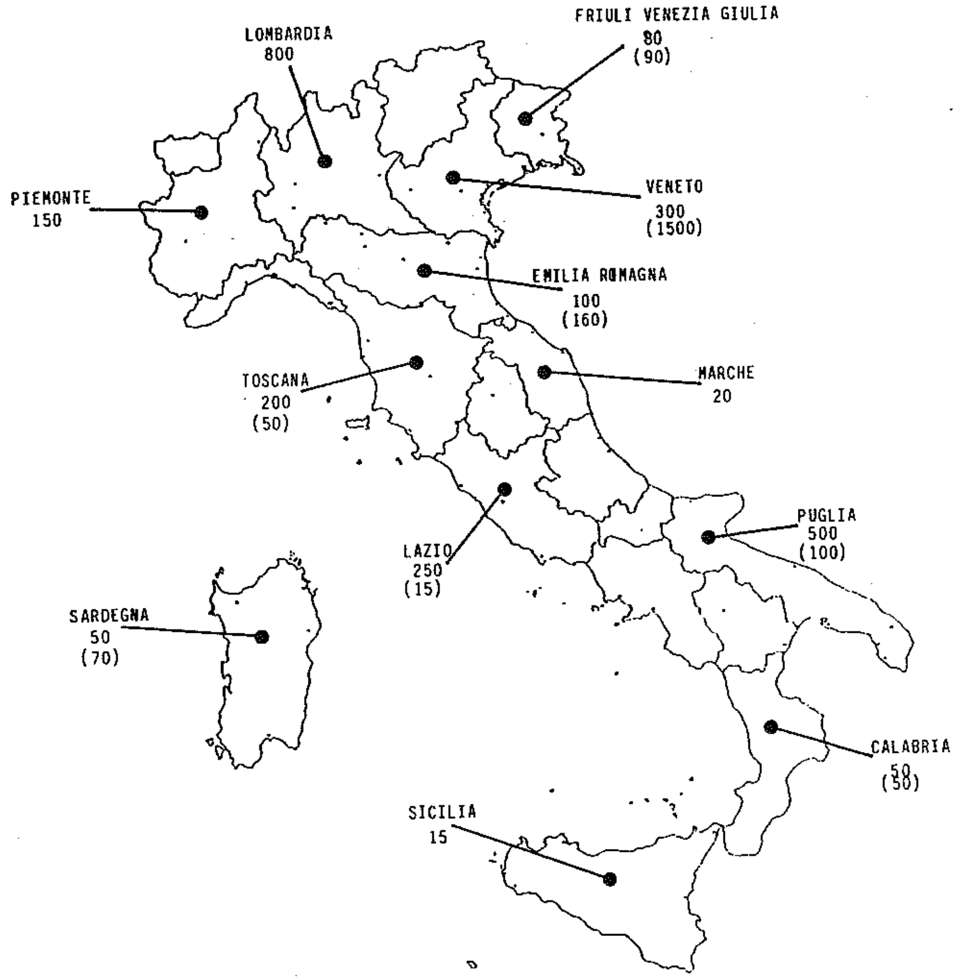


Figure 1. Eel production by intensive and extensive culture in Italy in 1989. Totals: intensive 2,500, extensive 2,000 tons. Extensive figures in parantheses.

Home Market and Foreign Trade

The eel market is characterised by a home demand concentrated in the month of December (in fact, eel represents a traditional Christmas dish) and by a foreign demand coming mainly from the countries of central and northern Europe (Germany, the Netherlands and Denmark).

As far as home demand is concerned, a survey carried out by Maestrelli and Senesi in 1983 showed that almost 20% of Italian families regularly eat eel, with a maximum level of 25% in southern Italy and in the main islands, whereas in northern and central Italy tne consumption is lower (about 18% and 15% of the total consumption respectively).

The product for the home market is mainly sold as fresh fish, although the consumption of the finished goods, such as marinated and smoked eels, is increasing.

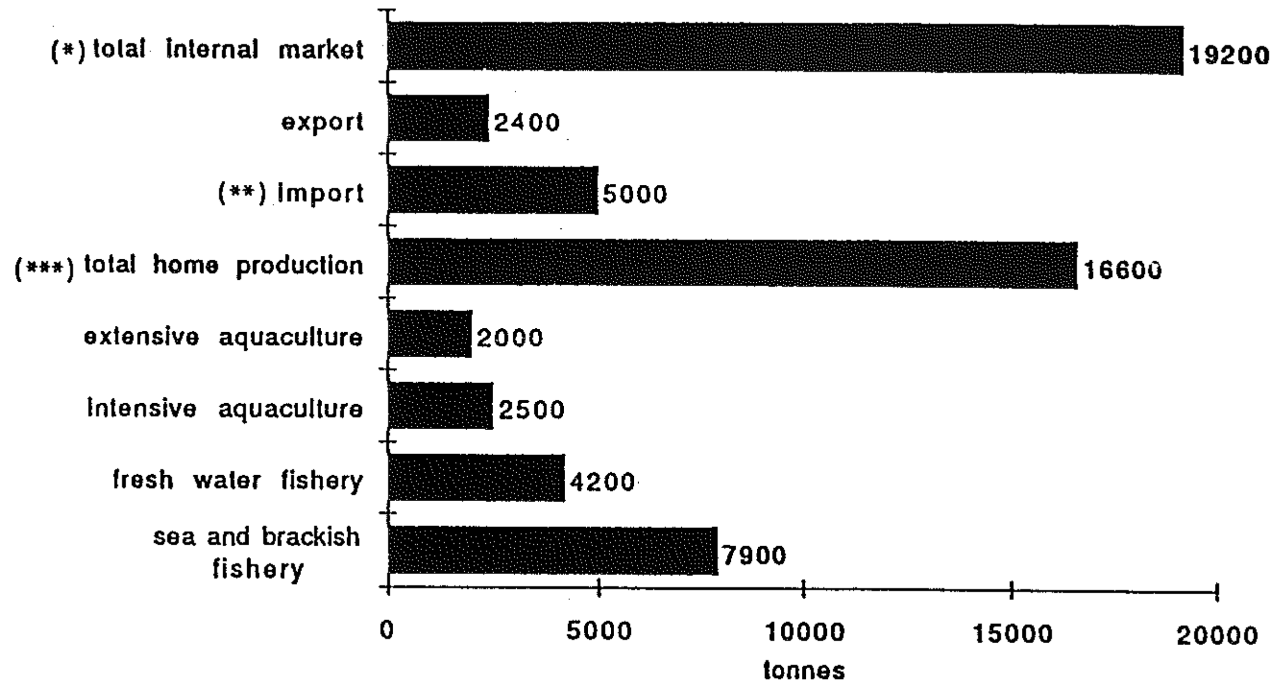
The product to be exported is purchased from fishing dealers who buy live eel in Italy and export them for smoking in the importing countries.

The 16,600 tons produced from aquaculture plus fishery, are partially exported (2,400 tons). The imported 5,000 tons are partially represented by young yellow eel for ongrowing and cover about one quarter of the internal market as shown in Figure 2. Aquaculture accounts for 27% of the national production, supplying 23% of the home market.

As far as foreign trade is concerned, the balance import-export is unfavourable for Italy; in fact, exports amount to less than half the imports. Such a deficit may be explained, on the one hand, by the home demand, which is very high at Christmas-time, and on the other hand, by the need for eel farms to import juveniles, mainly young yellow eels, which is the stage of development from which eel farming usually begins.

Prices

Table 1 shows producer prices, wholesale prices and retail prices relating to eel. These prices are extremely



(*) total home production + import - export
(**) including also elvers and young yellow eels
(***) extensive + fishery

Figure 2. Italian eel production (tons) in 1989. Total internal market includes imports, excludes exports. Import includes elvers and young yellow eels. Total home production comprises aquaculture fishery.

variable, since the price system relating to this species fluctuates upon a whole series of factors such as market size, season, place of origin and market place.

Marketable size — The "capitone" (1-2 pieces/kg) is sold at higher prices than the "buratello" (5-7 pieces/kg): such a difference is about Lit. 2,600-3,000/kg.

Season — Price trend, as shown in Figure 3, varies according to season, with an increase during Easter and summer holidays, a fall in autumn and a peak at Christmas-time, because of the traditional demand for the "capitoni".

Place of origin — Prices vary also according to the place of origin: eel coming from lagoon valliculture costs Lit. 1,000-2,000/kg more than the eel from intensive farms, because of believed better organoleptic qualities. In a different way, the eel caught by fishermen is sold at lower prices (in this case, too, Lit. 1,000-2,000/kg) compared to the eel coming from eel farms; such a phenomenon may be interpreted as a sign of poor contractual power of the fisherman compared to the fish farmers.

In Italy many eel farmers are associated to the "Accademia Italiana dell'Anguilla" (AIDA), which works in cooperation with the "Associazione Piscicoltori Italiani" (API) which fosters, among other things, a cartel policy by fixing, within the company, the prices of farmed fish. Imported eel is generally sold on the market at lower prices than those previously fixed; moreover, this sitution makes it possible to maintain prices.

Prices vary a great deal according to the districts where the eel is put on the market: in 1986, for example, the average unit price of the eel sold on the wholesale market of Marche (central Italy) reached Lit. 13,000/kg, whereas in Campania (southern Italy). the unit price was equal to Lit. 5,000.

Economic observations

Market research has been carried out, as an example, on two intensive on-shore eel farms of different dimensions. According to the data obtained from this survey, the first eel farm has a scale of operations equal to 25 tons and the second one to 100 tons.

Table 2 shows, through the production cost analysis, the internal rate of return (IRR) and the payback

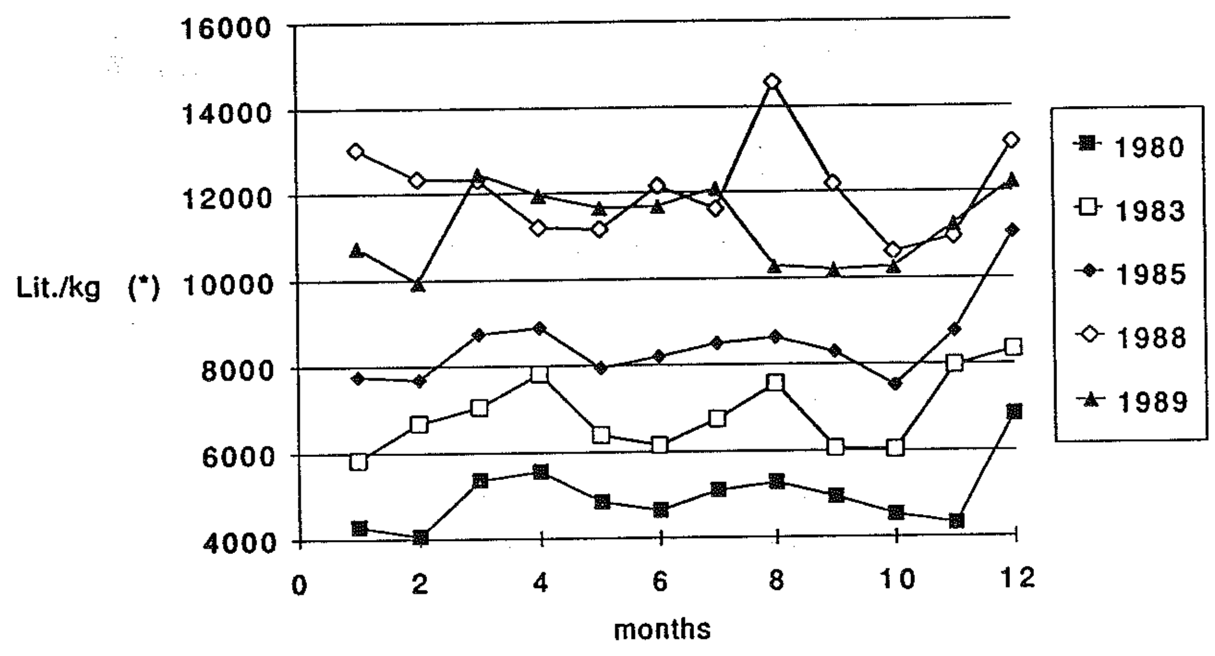


Figure 3. Main variation in eel wholesale prices (Lit./kg) from 1980 to 1989. 1 US $ = 1,600 Lit.

period (PbP) that the economic performance of eel production is related to the scale of operations. If we assume that an ex farm price is Lit. 10,000/kg with a net profit of Lit. 953 and Lit. 1,314, respectively, the IRR is equal to 8.7 and 16.4, while the PbP is equal to 5.8 and 4.8, respectively.

In the following, we have made some hypotheses with reference to the above-mentioned methods of fish farming:

—food conversion ratio = 1:2.5-3
—average weight of fish = 250gh
—mortality rate = 10%
—full-time employment = 0.7

As far as eel in polyculture is concerned, in Table 3 a semi-intensive farm and two extensive farms in valliculture have been taken into account having traditional stock and animal yields of 10, 30 and 110 tons respectively and producing eel, sea bass, sea bream and mullet at the same time.

Although the results may not be clear-cut with a survey carried out on two facilities only, there is an indication that the scale of operation can be considerable in terms of profitability as the IRR grows from lower to higher extensive production: from 2.9% to 3.5%; the PbP, too, shows similar results, i.e. from 19.5 years to 16.2.

Productivity is low, as is well-known, but in order to improve it, another example has been taken into account, namely increase in production by feeding the stock and turning into a semi-intensive system. In this way, it is possible to reach 700kg and profitability shows an IRR of 5.2 with a PbP of 10.9 years. The valliculture in question reaches a production level of 10 tons of fish and it is manned with 1.5 labour units.

The hypotheses relating to polyculture are the following:

—food conversion ratio = 3.5:1
—average weight of fish = 350g
—mortality rate = 50%
—stocking density kg/ha = 1,000 (10t), 110 (30t), 110 (110t)
—full-time employment = 1.5 (10t), 4 (30t), 12 (110t)

CONCLUSIONS

In Italy, eel is farmed both in fresh water and in brackish waters and in intensive systems or where water temperature is suitable. After an unfavourable period, due to diseases which affected the eel in the 1970s (mainly, Argulosi), extensive eel farming was reduced in valliculture, not reaching a good production again until the end of the 1980s. As far as intensive eel farming is concerned, however, eel production has increased again, mainly in the districts where either mild waters or warm effluents are available.

The production process starts either with wild glass eel (n. 1,500-3,000/kg) or young yellow eels (n. 20-50/kg), which however limit industry levels, because of their limited supply. In Italy this problem has not been solved yet, because there are only 11 nurseries of which 7 are productive.

On the other hand, although prospects for the growth of the Italian demand are not too strong, the supply is still very limited, compared with the actual demand for consumption. The market is promising thanks to large imports and a good amount of exports.

The real constraints to production growth seem to be the supply of acclimated young yellow eels and glass eel. The estuarine catch is decreasing every year, because of regulations and, according to fishermen, scarcity along the Italian coast. Evidence of this is given by increasing imports not only of the glass eel, but also of young yellow eel as well as of the final product itself. One of the main reasons for this situation is disease caused by parasites which led to a decrease in eel farms' productivity.

On the other hand, the production of young yellow eels must be increased. After reaching this goal, eel production may be developed even further, since there are many opportunities to expand it as an additional income source for agricultural undertakings, wherever water quality and technology transfer make this possible.

In spite of the fact that eel farming is still mainly carried out in the northeast of Italy, for historical reasons, the regions of southern Italy seem to be increasingly interested in developing this form of fish culture. This is due to unexploited agricultural and marginal areas, where good quality water, at a temperature of 18-25°C, is available throughout the year.

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Table 1. Eel prices per kg in Lit. (US$ in parentheses).

	Lowest	Highest
Ex farm	13,000 (8.12)	16,000 (10.00)
Wholesale buying	14,000 (8.75)	17,000 (10.62)
Final consumer in major market	18,000 (11.25)	20,000 (12.50)

Table 2. Intensive onshore eel ongrowing: cost per kg in Lit. (US$1 = 1,300 Lit.) for two scales of operation.

Costs and income	Scale of operation (tons) 25	100
Elvers and young yellow eels	2,800	2,800
Feed	3,200	3,200
Labour	840	780
Energy	350	330
Other	550	400
Depreciation	990	900
Interest	387	376
Total cost per kg	9,047	8,686
Ex farm price per kg	10,000	10,000
Net profit or loss per kg	933	1,314
Internal rate of return	8.7%	16.4%
Payback period (years)	5.8	4.8

Table 3. Polyculture: cost per kg (yield = 110kg/ha of pond) in Lit. for three scales of operation (US$1 = 1,600 Lit.).

Costs and income	Scale of operation (tons) 10	30	110
Elvers and young yellow eels	6,000	4,500	4,500
Feed	4,000	0	0
Labour	4,200	4,800	4,500
Energy	800	500	400
Other	300	600	500
Depreciation	3,060	450	410
Interest	765	505	495
Total cost per kg	19,125	11,055	10,805
Ex farm price per kg	22,000	13,700	13,700
Net profit or loss per kg	2,875	2,645	2,895
Internal rate of return	5.20%	2.90%	3.50%
Payback period (years)	10.9	19.5	16.2

An effective biofilter system for eel culture in closed recirculating systems

by

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An eel farm producing 100 tonnes per annum was established in 1989 in the Dutch village Noord-Scharwoude. It operates as a closed circuit and produces eel up to table size in two stages: fingerling rearing from glass eel and fattening.

The fattening circuit is fitted with a Stählermatic biofilter system operating as a combined fixed-film-activated sludge reactor with aeration and sludge stirring by a specially shaped cell-wheel. A standard fixed-film (trickling filter) and a triangle filter are used in the fingerling circuit.

The existence of two different biofilter systems in one farm offers a good opportunity for comparison of performance. The trickling filter in the fingerling circuit can be given a maximum loading of 5.7 g feed per m^2 per day. In this case a concentration of ammonium of 1-2 mg/l and of nitrite of 5-8 mg/l can be maintained.

In the Stählermatic biofilter the load is distributed between the surface of the cell-wheel and the activated sludge. In the case of a sustained load of sludge of 275 g feed per kg SS per day the maximum load of the cell feed surface was 31.7 g feed per m^2 per day. The water quality attained was considerably better at ammonium 0.1-0.4 mg/l and nitrite between zero and 0.2 mg/l.

The suspended solids in the water, which are often a serious problem in recirculating systems, were in all cases distinctly lower in the fattening circuit using the Stählermatic filter than in the fingering system with standard filtration. Another advantage of the Stählermatic system was the much higher process stability.

At the end of 1990 the eel farm attained a standing crop of 28 tonnes, which was 93% of the target.

The full paper is published in Aquacultural Engineering 1993 (12).

Effects of sex steroids on gonadotropin synthesis and secretion as well as ovarian development in female Japanese silver eel *Anguilla japonica*

by

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The effects of sex steroids on gonadtropin (GtH) synthesis and release as well as ovarian development in female silver eel were investigated. Multiple injections of 17β-estradiol or testosterone stimulated GtH synthesis and secretion as well as ovarian development, testosterone was more effective than estradiol in this respect; multiple injections of LHRH-A ineffective on pituitary GtH content and ovarian development. Multiple implantations of 17β-estradiol or testosterone stimulated the increasing of pituitary GtH content, however, no significant changes in serum GtH levels were detected at the sampling times used. Multiple implantation of 17β-estradiol resulted in marked increase in serum vitellogenin content, but ovarian development was not significantly stimulated; whereas multiple implantations of testosterone were effective in stimulating an increase in ovarian development, although there were no significant differences in the serum vitellogenin level when compared with the controls. Multiple implantations of testosterone in combination with LHRH-A did not further stimulate pituitary GtH content or ovarian development. Within the experimental period of 80 days, the effects of multiple implantations of testosterone in stimulating ovarian development were similar to multiple injections of testosterone, however, the times of implantation were much less than injection. The application of the heterologous radioimmunoassay for eel GtH measurement was further validated by the demonstration that hypophysectomy abolished the increases in serum GtH levels normally found following treatment of the eel with 17β-estradiol. These results demonstrate that serial injections or implantations of testosterone alone can stimulate the brain-pituitary-ovary axis of the eel to stimulate GtH synthesis in the pituitary and to induce ovarian development.

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The distribution of *Anguillicola* in Sweden and its association with thermal discharge areas.

by

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ABSTRACT

The prevalence and intensity of *Anguillicola* sp. infections in the swimbladder of the European eel *Anguilla anguila* are presented. A total of 8,081 eels form 11 lakes and 12 sites along the Swedish coast, four of which are affected by thermal discharges from nuclear power stations, were examined during the period 1987-1990. In addition, eels examined at the Veterinary Institute and reports of *Anguillicola* by local fishermen are included in the study. Apart from two records of *Anguillicola* (prevalence <1%) from the Swedish west coast, the parasite has only been found in yellow eels from three areas, all affected by thermal discharges. Outside the Barsebäck nuclear power plant on the south-west coast infection prevalence was low during the years 1987-1988. Infections then declined and were absent in 1990. During late 1990, *Anguillicola* also appeared in consecutieve samples of eels from the thermal discharge area outside the Forsmark nuclear station on the Baltic coast north of Stockholm. At present this is the northernmost finding of the parasite. However, the most heavily infected area if Hamnefjärden which receives thermal discharges from the nuclear power plant in Oskarshamn on the Swedish south-east coast. Here the infection has gradually increased form 7% in 1988 to 68% in 1990. *Anguillicola* has also been reported from migrating silver eels in areas unaffected by the thermal discharges. As yellow eels from these area as still are uninfected and the findings are concentrated to the vicinity of Oskarshamn it is possible that the thermal discharge area serve as a transmission focus for infected silver eels.

INTRODUCTION

In the beginning of the 1980's nematodes of the genus *Anguillicola* (Yamaguiti 1935) were recorded for the first time in the European eel, *Anguilla anguilla.* The life cycle of anguillicolids includes alternate generations in different host species. They are regarded as freshwater parasites generalistic at the intermediate host level. The adults live in the swimbladder of the eel where they feed upon the host's blood. The ovoviviparous females give birth to first stage larvae (L_1) which as second stage larve (L_2) reach the intestine of the eel via the pneumatic duct. They are released to the ambient water with the faeces of the host and infect various species of copepods which act as the intermediate host. In the haemocoel of the copepods the parasites transform into third stage larvae (L_3). Eels are infected by feeding upon the first intermediate host or on fish acting as paratenic hosts (Wang & Zaho 1980; Haenen *el al.* 1988; De Charleroy *et al.* 1990).

Remarkably, the genus *Anguillicola* has been introduced to Europe along with intercontinental transports of eels for stocking and managing purposes.The first record was made in 1982 by examination of an eel from an Italian lake situated outside Rome (Paggi *et al.* 1982). It was first identified at the Australian species *A. australiensis*, but following a taxonomic comparision it proved to be *A. novazealandiae*, a common and widespead parasite of eels in New Zealand. This way, the origin of the parasite was confirmed and it could be concluded that it was introduced (Moravec & Tarachewski 1988). Later on the related species *A. crassus* was reported from eels in Germany (Neumann 1985). In contrast to *A. novazealandiae A. crassus* was probably introduced with imported Japanese eels, *Anguilla japonica*, from Taiwan (Neumann 1985). The colonization of *A. crassus* has since then been epidemic and during the 1980's it has been reported from several Western-European countries (Belpaire *et al.* 1989a). In Scandinavia *Anguillicola* has only been recorded from Denmark (Køie 1988) and Sweden (Hellström *et al.* 1988; Lindesjöö 1988). The first record in Sweden was from transit consignments of Polish eels on their way to Germany in 1988. At about the same time, *Anguillicola* was found in a migrating silver eel off the Swedish east cost (Hellström *et al* 1988) and among yellow eels from Hamnefjärden, a brackish water area heated by thermal discharge from the Oskarshamn nuclear power station on the Swedish east cost (Höglund *et al.* 1989).

Due to the first records of *Anguillicola* and reports on its rapid spread in Europe, a careful examination of the swimbladder was included in the sampling routines by institutes in Sweden dealing with fish diseases and eel management. In the present paper, the status of the *Anguillicola* situation in Sweden until December 1990 is presented.

MATERIALS & METHODS

Sampling areas

The eels examined were captured in coastal areas and lakes as shown in Table 1. and Figure 1. As indicated in Figure 1 there is a gradually decreasing salinity of the water along the Swedish coast from the west to the north-east. Likewise there is a decline in water temperatures, those in Nordic coastal areas are lower than in lakes in central-Europe. As shown in Figure 1 some of the coastal areas receive thermal discharge from nuclear power stations. This raises the temperatures in the discharge areas to a level of 8-10°C above ambient.

Some Baltic sites as well as some of the lakes included in this study have on several occasions been stocked with yellow eels mainly captured at the Swedish west coast,but also with elvers fro France and Great Britain.

Sampling procedures

The majority of the eels from the coastal areas were captured and examined by staff at the Coastal Water Laboratory at the Swedish Environmental Agency, as a part in a large scale monitoring programme on the biological effects of cooling water discharges from nuclear power stations, whereas those from the lakes were examined by staff at the Institute of Freshwater Research. In general the eels were captured with fyke nets. Body length and weight were recorded. Swimbladders were dissected and exmained for parasites. Numbers of parasites were recorded and in most cases speciments were fixed and presvered in 70% alcohol. Additional samples of eels examined at the Veterinary Institute as well as specimens of parasitised eels reported by local fishermens are also included in the study.

RESULTS

Distribution of Anguillicola *sp. in Sweden*

As shown in Table 1 all eels sampled in freshwater localities were found to be uninfected. Thus the distribution of *Anguillicola*-infected yellow eels in Sweden was restricted to certain coastal sites. Except for two records at the Swedish west coast (prevalence <1%) parasitised eels have so far only been recorded from three sites, sall of which are affected by thermal discharges from nuclear power plants. In Barsebäck (site S in Figure 1) in the most south-western part of Sweden, there was a low degree of infection rcorded in 1988 and 1989. *Anguillicola* then disappeared and in 1990 no records were made.

On the other hand, in the thermal discharge area outside the Oskarshamn nuclear power plant on the Swedish south-east coast (site P) the prevalence of infection gradually increased from 7% in 1988, when it was first recorded, to 68% in 1990. The mean number of parasites per fish increased from 0.3±1.4 (SD) in 1988 with a maximum of 17 *Anguillicola* in one eel to 4.9±7.3 (SD) in 1990 with a maximum number of 57 parasites. In 1988, the prevalence of infection was significantly higher in samples from the period July-December than compared to January-June. Although there was a tendency for the reversed pattern the following two years these differences were not significant (Figure 2). However, the mean number of parasites per fish differed significantly between these periods (Figure 2), both in 1988 when it was higeher during the second half of the year and in 1990 when it was higher during the first half. In 1989, no significant difference was noted. Oskarshamn in 1990 was the most heavily infected site in Sweden.

In August 1990 *Anguillicola* also appeared for the first time in 1 eel out of 84 captured in an area affected by the thermal discharges from the Forsmark nuclear power plant on the east cost of cental Sweden (site C, Figure 1). In October the same year, the prevalence of infection was increased to 16.3% (n=61) and in December to 43% (n=13). This was the northernmost finding of *Anguillicola*. In addition to these records, *Anguillicola* was also found in migrating silver eels as shown in Table 2. These findings were concentrated on the Swedish south-east coast (Figure 1.). Finally, eleven samples, totally 880 eels, collected on the west coast for stocking purposes, were examined. Mean length of the samples ranged from 387 to 414mm. No *Anguillicola* were found among 877 eels captured at the Swedish west coast for stocking purposes.

Prevalence and intensity of infection in relation to fish size

Although the prevalence of infection in the Oskarshamn material seemed to exhibit a convex pattern in relation to fish length both in 1989 and 1990, with a maximum degree of infection of fish in the size interval 500-699mm, these differences were not significant (Figure[3] a-d). However, the mean number of parasites per fish in different length groups of eels differed significantly in 1990, but not in 1989 (Figure[3] c-d).

DISCUSSION

Although freshwater localities in Sweden were uninfected, records of the non-indigenous parasite *Anguillicola* sp. have been made among eels in certain coastal areas. Apart from two records (prevalence <1%)

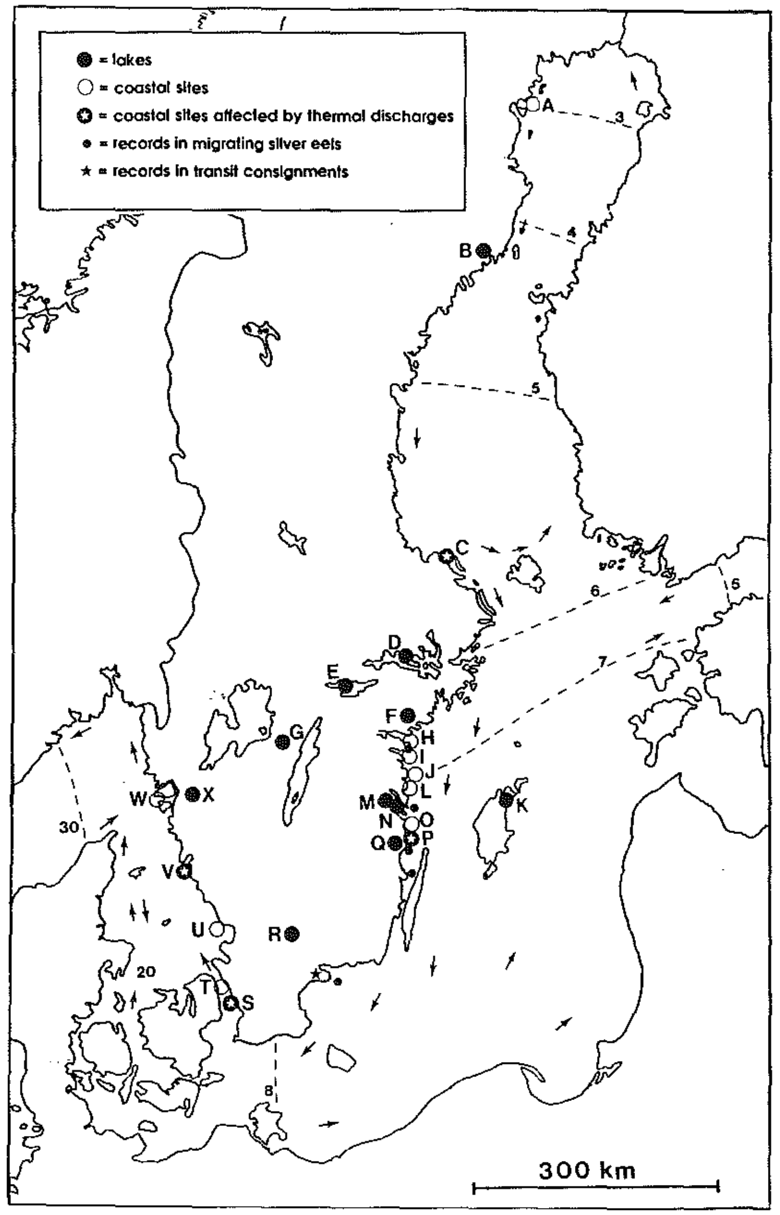

Figure 1. Sampling sites for eels examined for *Anguillicola* sp. in Sweden during 1987-1990. Records of *Anguillicola* in migrating silver eels are indicated by dots in the figure. Arrows denote the main direction of the water flow whereas the dotted lines denote borders for given salinites (‰) of the surface water.

from the west cost, *Anguillcola* sp. infected yellow eels have only been found at three sites, all of which are affected by thermal discharges from nuclear power stations. Outside the Barsebäck nuclear power station in the most southern part of Sweden occasional records were made during the period 1988-89. Then the infection disappeared. On the other hand, the infection has been established in the thermal discharge area outside the Oskarshamn nuclear power station situated at the Swedish south-east coast. During 1990 the prevalence of infection was 68% with a mean number of 4.9 parasites per fish recorded in this area. Recently, eels from the Baltic coast outside the Forsmark nuclear power station in Central-Sweden were also found to be infected. In addition records of *Anguillicola* have been made in migrating silver eels captured along the south-east coast.

The rapid colonization by *Anguillicola* in most West-European countries mainly considered as being due to man-made trading of eels for stocking purposes (Belpaire *el al.* 1989a, b; Koops & Hartmann 1989; Kennedy & Fitch 1990). Whether *Anguillicola* was spread to the Baltic due to the natural migrations of eels or together with its intermediate and paratenic hosts, or introduced, is at present almost impossible to conclude. Young yellow eels are on a regular basis transported from the Swedish west and south coasts to be stocked on the east coast and in many lakes. Although *Anguillicola*-infected eels were not recorded in

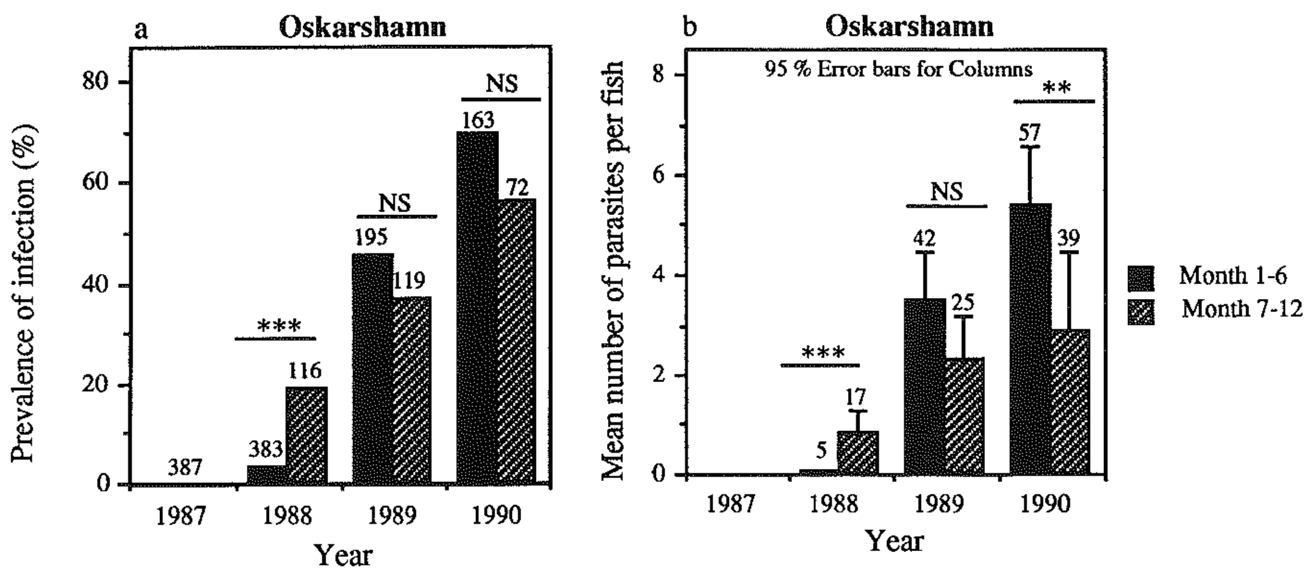

Figure 2. (a) Prevalence of *Anguillicola*-infection and (b) mean number of parasites per eel in Oskarshamn (site P). Values in (a) were tested with X^2-test and in (b) with Mann Whitney U-test. Numerals in (a) denote the sample size and in (b) the maximum number of parasites observed in one eel during each period.

such stocking material in 1987, this transport system may provide an efficient mechanism for spreading of the parasite over vast areas, especially as guarantees can seldom be given on the origin of these eels. In addition, stocking with elvers has been performed both in Oskarshamn and Forsmark during the 1980's.

The latest stocking at Oskarshamn before infection was first recorded was made in 1984 with elvers from the Swedish west coast. The same year, 12,000 fingerlings from the Severn in England were released in Forsmark after being in quarantine in a fish farm in south-west Sweden. On the other hand, *Anguillicola* has also been recorded in migrating silver eels at different places along the Swedish east coast. Consequently, the possibility of natural spreading due to marine migration of infected eels cannot be excluded. However, yellow eels in these areas are still uninfected and the majority of their findings of infected silver eels were made near the most heavily infected site in Sweden. It therefore seems possible that the silver eels were infected in Oskarshamn before they started to migrate, in which case this area serves as the transmission focus. If so, the records made in the silver eels north of Oskarshamn would strengthen by hypothesis of Westin (1990), that stocked eels loose their ability to find the outlet of the Baltic as the main migration route normally is in a south-west direction.

The survival and development of *Anguillicola* in various intermediate hosts has been shown to be temperature dependent (De Charleroy *el al. 1989; Petter et al.* 1990). At present there is a paucity of information concerning the role of temperature for the development of the stages in the final host. However, as *Anguillicola* spp. are adapted to tropical or subtropical conditions it seems likely that the water temperature is a critical factor influencing their capacity to infect and develop in the eel. The distribution of *Anguillicola* in yellow eels in Sweden is almost confined to sites affected by thermal discharges. This is an indication that the conditions required to complete life cycle in Swedish waters are only fulfilled in such areas. As migrating silver eels have been found elsewhere, the potential role of using *Anguillicola* as a biological tag in Swedish coastal areas is evident. However, it is too early to make any conclusions until further sampling and laboratory tests on the temperature-related infection capacity of *Anguillicola* have been performed.

In conclusion during the period 1987-1990, *Anguillicola*-infected yellow eels in Sweden have been recorded mainly in coastal sites receiving thermal discharges. It is therefore suggested that the conditions required to complete the life-cycle are fullfilled only in these areas. If so, further outbreaks of *Anguillicola* in Sweden would be restricted. However, findings of *Anguillicola* have also been made in migrating silver eels captured elsewhere and at present conclusive evidene about the water temperature acting as a limiting factor is lacking. Thus, further sampling and experimental work are needed in order to evaluate the temperature related development of *Anguillicola.*

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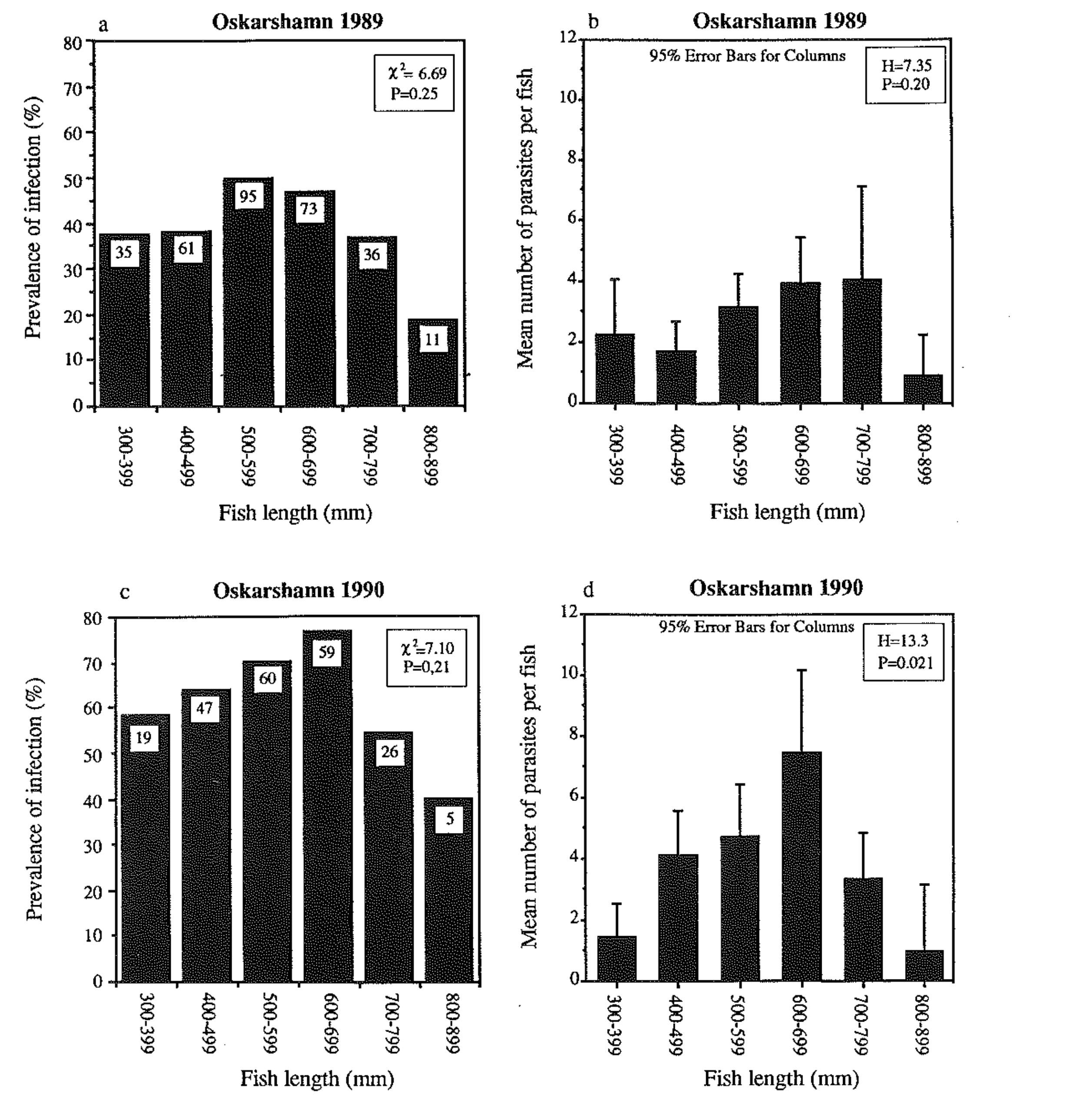

Figure 3. (a & c) Prevalence of *Anguillicola*-infections and (b & d) the mean number of parasites per fish in different length intervals of eels in Oskarshamn in 1989 and 1990. The numerals in the bars in (a & c) denote the sample size.

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Table 1. Sampling stations of eels examined for Anguillicola sp. in Sweden during the period 1987-1990 (cf Figure 1).

Site	locality	year	n	silver (%)	eels mean (mm)	range (mm)	prevalence (%)
A Storfjärden	coastal	1987	38	0		439-767	0
		1990	8		710	619-857	0
B Ängersjön	lake	1988	3	0	670	608-781	0
C Forsmark	coastal	1988	20	0	691	580-900	0
		1989	150	0	782	440-1310	0
		1990	226	<1	612	420-915	8
D Mälaren	lake	1987	10	100	806	748-886	0
		1988	118	0	595	400-1000	0
		1989	14	0	624	488-874	0
		1990	24	0	642	487-990	0
E Hjälmaren	lake	1987	10	100	844	738-944	0
		1989	97	0	583	395-712	0
		1990	100	9	538	319-755	0
F Angen	lake	1987	66	0	773	519-874	0
		1988	6	0	449	345-540	0
		1989	38	11	652	509-869	0
G Ymsen	lake	1990	104	4	468	314-653	0
H Jonsbergsviken	coastal	1987	5	0	531	507-560	0
		1988	2	0	519	513-525	0
		1989	1	0	397		0
		1990	59	0	533	349-710	0
I Aspöja	coastal	1988	10	80	428	370-500	0
J Harstena	coastal	1987	102*				0
		1990	95	0	639	350-850	0
K Fardume träsk**	lake	1987	44	100	553	140-730	0
		1988	38	100	596	246-770	0
		1989	28	100	675	418-839	0
		1990	158	100	672	382-848	0
L Kvädöfjärden	coastal	1987	119	0	575	430-777	0
		1988	206	1	611	452-855	0
M Ommen	lake	1987	49	2	511	368-800	0
		1989	27	0	504	440-680	0
		1990	52	0	513	366-675	0
N Frisksjön	lake	1987	28	0	459	366-577	0
		1990	110	1	500	382-649	0
O Marsö & Dragskär	coastal	1988	20	0			
		1989	20	5	588	424-658	0
		1990	20	0			0
P Oskarshamn	coastal	1987	387	3	474	279-881	0
		1988	499	9	528	259-1001	7
		1989	314	3	568	310-975	42
		1990	235	6	582	308-908	66
Q Götemaren	lake	1987	4	0	531	488-606	0
		1989	91	9	468	372-679	0
R Flåren	lake	1989	26	84	716	608-846	0
S Barsebäck	coastal	1987	198	0	431	289-692	0
		1988	162	0	423	300-589	1
		1989	100	21	551	355-805	5
		1990	130		570	308-878	0
T Öresund	coastal	1987	77		405	300-500	0
		1988	33	24	380	280-500	0
U Halmstad	coastal	1987	153	0	486	215-641	0
		1988	109	2	484	279-713	0
V Ringhals	coastal	1987	207	0	447	303-687	0
		1988	224	1	436	313-760	0
		1990	110		470	340-900	0
W Bohuslän	coastal	1987	803		400	300-500	0
		1989	447			300-500	<1
		1990	317			300-500	0
X Göta älv	river	1987	31		337	265-444	0
		1988	9		284	270-315	0

*Based on material from St: Anna-Kalmar.
**Means based on the total catch each year.

Table 2. ***Anguillicola*-infected silver eels reported by local fishermen in Sweden 1988-1990 (cf. Figure 1).**

Site	Year	Month	Prevalence of Parasites
1 Aspöja	1988	December	
	1990	October	2/60
2 Måskår	1989	December	5/14
2 Oskarshamn-Loftahammar	1988	December	1/1
4 Vållö	1990	November	10/12
5 Sillnäs udde	1990	October	1/1

Appearance of eel diseases in Ohrid Lake

by

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ABSTRACT

From August 27th to September 15th, 1986 a mass infection and death of the eels in Lake Ohrid was observed. The weight of the eels was from 500 to 1500g aged from 6 to 10 years.

On the skin of the diseased and dead eels were white oval spots and necrosis. The diseased eels were slack, slow-moving and were swimming close to the surface.

On analysis of the dead eels the bacteria *Pseudomonas punctata* and a great number of the parasite *Echinorhyncus truttae* were found.

INTRODUCTION

Lake Ohrid is situated in the south-west of Yugoslavia on the border with Albania. It is a very old lake with a relict flora and fauna. The dominant fish in the lake are salmonids, cyprinids and eels. Yield of the eels is 10-20 tonnes per year. Lake Ohrid discharges through the river Drim and until 1965 when the river was dammed, a natural ascent of elvers took place. Since then the lake has been stocked with elvers mainly from France, Belgium and Italy. No diseases were recorded before 1986.

MATERIALS AND METHODS

Samples of dying and dead eels were collected by local fishermen and a team from the Veterinary Institute in Skopje, where the fish were analysed. Eels weighed 500 to 1500g and were aged from 6 to 10 years. The temperature in the lake was 25-26°C. Patho-anatomical, histopathological and bacteriological investigations were made on the eels.

RESULTS AND DISCUSSION

The eels behaved abnormally. Some moved into the sheltered part of the lake, close to the shore, while others just came to the surface. The diseased eels were slack and their swimming was slow with irregular movements.

The eels had blue and white spots on the skin and reddish speckles, especially on the abdomen and the fins. In some of the spots both subcutaneous and muscular tissue were destroyed. Most of the internal organs did not show any infections though some of the eels had inflammations around the anus. The intestines of about 60% of the eels were heavily infested withe the parasite *Echinorhynchus truttae* causing perforation and inflammation.

In the bacteriological investigation *Pseudomonas punctata* was isolated and identified.

This is the first time that diseases have been reported from the lake. After the natural ascent had been replaced by stocking with elvers from many localities, it is reasonable to assume that some of these elvers has been carriers of the diseases. The high water temperatures and the infection with the parasite *Echinorhynchus truttae* appear to have exacerberated disease caused by bacterial infection.

Our observations and results are in accordance with those of Schaperchlaus 1941, 1954, Plancic 1952, Tomasec 1953, Amlacher 1970, Atsuchi 1974 and Forest 1976.

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Development of *Anguillicola* infestations in some Danish lakes and inlets

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The spreading of *Anguillicola* in some infested Danish lakes and inlets has been followed in 1989 and 1990. In all places an increasing percentage of the eels was infected. In two of the lakes cartilaginous swimbladders were found for the first time.

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